Ministry
of the
Environment

Ontario

Water Resources
Report 12

Hon. Harry C. Parrott, D.D.S., *Minister*
Graham W.S. Scott, *Deputy Minister*

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Geology and Water Resources of the East and Middle Oakville Creeks IHD Representative Drainage Basin

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Ontario

WATER RESOURCES
REPORT 12

Geology and Water Resources of the East and Middle Oakville Creeks IHD Representative Drainage Basin

By
Gunther Funk

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

Toronto Ontario

1979

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PREFACE

The East and Middle Oakville creeks drainage basin was one of five drainage basins in southern Ontario, studied as part of the Ministry's contribution to the International Hydrological Decade (IHD) program. These basins were selected as being representative of much larger physiographic regions in the Province. This report describes the hydrogeology of a drainage basin situated in a glaciated area characterized by a bedrock escarpment overlooking a clay and clay-till plain. The data for this report were gathered during the International Hydrological Decade, 1965-1974. The study was completed by the Water Resources Branch of the Ministry.

Toronto, May 1979

G. H. Mills, Director
Water Resources Branch

ENGLISH - METRIC (SI) FACTORS

to convert	to	multiply by
inches (in)	centimetres (cm)	2.540
feet (ft)	metres (m)	0.305
miles (mi)	kilometres (km)	1.609
square miles (mi^2)	square kilometres (km^2)	2.590
cubic feet/second (cfs)	litres/second (l/s)	28.316
Imperial gallons (Ig)	litres (l)	4.546
Imperial gallons/day (Igpd)	litres/second (l/s)	5.262×10^{-5}
Imperial gallons/day/ft^2 ($Igpd/ft^2$)	metres/second (m/s)	5.663×10^{-7}
Imperial gallons/day/ft (Igpd/ft)	square metres/second (m^2/s)	1.726×10^{-7}
Imperial gallons/min (Igpm)	litres/sec (l/s)	.0758

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(in pocket)

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ABSTRACT

The geology and ground-water resources of the East and Middle Oakville creeks drainage basin have been studied as part of the Ontario Ministry of the Environment's contribution to the International Hydrological Decade Representative Basin program. This basin is representative of a larger physiographic area in southern Ontario characterized by a bedrock escarpment overlooking a clay and clay-till plain. Included in the study are original data and associated analyses describing the geology, principal aquifers and major water uses in the area and the results of a simplified hydrologic budget.

The geology consists of Upper Ordovician to Middle Ordovician shales, sandstones, limestones and dolostones which are exposed along the Niagara Escarpment. A mantle of glacial sediments have modified the surface topography above and below the Escarpment. Overburden thickness ranges from 0 to 35 feet above the Escarpment to 0 to 135 feet below the Escarpment.

The major aquifers in the basin are the Amabel Formation, a dolostone, and the Outwash and Channel Sand and Gravel deposits at the base of the Escarpment. These aquifers yield water supplies of quantity and quality adequate for most domestic and farm uses.

Additional domestic supplies are developed locally in sand and gravel lenses in the till sheets and in the upper weathered zone of the Queenston Formation, a shale. The wells finished in these units are for the most part shallow and often go dry during the summer months. The ground-water quality of supplies obtained from these wells is highly variable ranging from good to poor depending on the location and depth of the supply.

Baseflow, as a percentage of total streamflow, (for the interval 1968-69 to 1973-74) was estimated to be 38.2% (the equivalent of 4.93 inches precipitation/year) for the area including the Escarpment, 7.2% (0.65 inches) for the clay, clay-till plain below the Escarpment and 18.2% (1.89 inches) for the basin as a whole. Ground-water recharge for the basin was estimated to be 1.87 inches of precipitation per year.

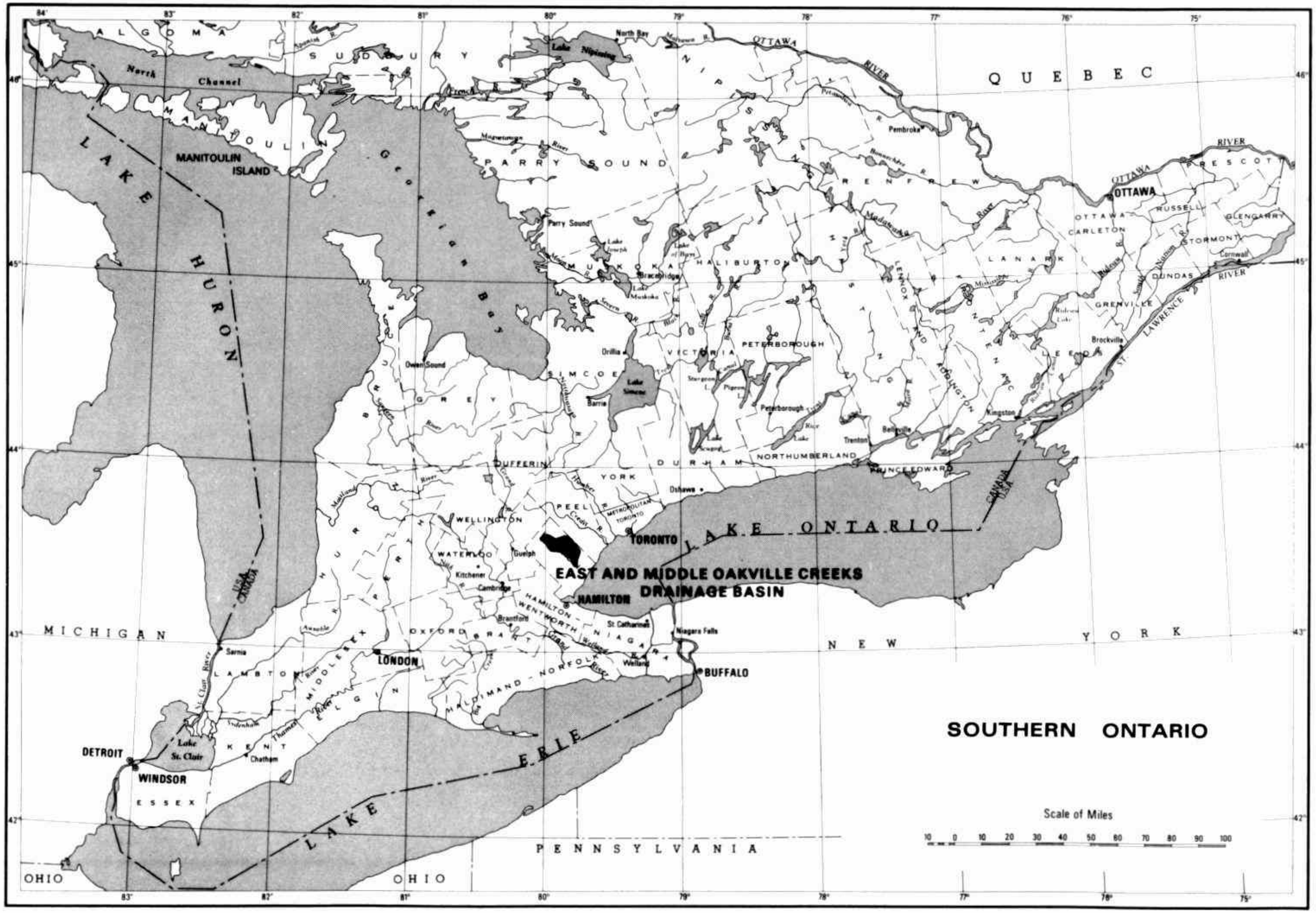


Figure 1. Location of the East and Middle Oakville creeks drainage basin in southern Ontario.

INTRODUCTION

PRESENT STUDY

This study, one of a series conducted on representative drainage basins in southern Ontario as part of the Ministry's contribution to the International Hydrological Decade (IHD) program, is a preliminary investigation of the ground-water resources in the East and Middle Oakville creeks drainage basin. The objectives of this study are:

(1) to determine the physical characteristics of the major geologic units in the basin,
(2) to assess the water-bearing properties of these different geologic units,
(3) to determine the occurrence, availability and quality of the ground waters, and
(4) to approximate the ground-water flow pattern.

The initial phase of this investigation consisted of examining water-well records kept on file at the Ministry of the Environment (MOE) office in Toronto, in order to establish site locations for the installation of observation wells, where geologic and hydrologic controls were limited. Field investigations included an inventory of existing wells, test drilling, hand augering, and the sampling of ground and surface waters.

Geologic control was provided by reference to existing publications, water-well records, detailed geologic logs kept for the observation wells and surficial mapping conducted in 1966, 1967 and 1974.

PREVIOUS INVESTIGATIONS

The Paleozoic stratigraphy underlying and in the vicinity of the study area has been described by Bolton (1957), Caley (1940), Cowell and Woerns (1975), Hewitt (1969), Liberty (1969), Liberty and Bolton (1971), Sanford (1969), Vos (1969, 1975), and Telford, Bond and Liberty (1974).

The Pleistocene geology has been described in Chapman and Putnam (1966), Cowell and Woerns (1975), Hewitt (1969), and Karrow (1963, 1968). A detailed soils map of Halton County was prepared for the Ontario Soil Survey by Gillespie et al (1971). The Scotch Block Reservoir area is discussed in detail in a consultant's report (E. M. Peto Associates Ltd., 1967).

The hydrogeology of the Oakville Creek drainage basin to the south is described by Ostry (1979) and the hydrogeology of the Blue Springs area to the west by Coward and Barouch (1978). The Guelph-Amabel Aquifer is described in Turner (1978). In addition, pumping-test data for wells on the Maple Mills Research Station property were supplied by Maple Mills (personal communication).

ACKNOWLEDGEMENTS

This study was supervised and completed under the direction of R. C. Hore, Supervisor of the Hydrology and Monitoring Section of the Water Resources Branch.

J. Coward, A. Babaris, P. Yu and R. C. Ostry are thanked for their help on various aspects of this study. All mechanical and carbonate analyses were conducted by D. Donohue of the Hydrology and Monitoring Section.

In addition, the author wishes to thank local residents for their co-operation.

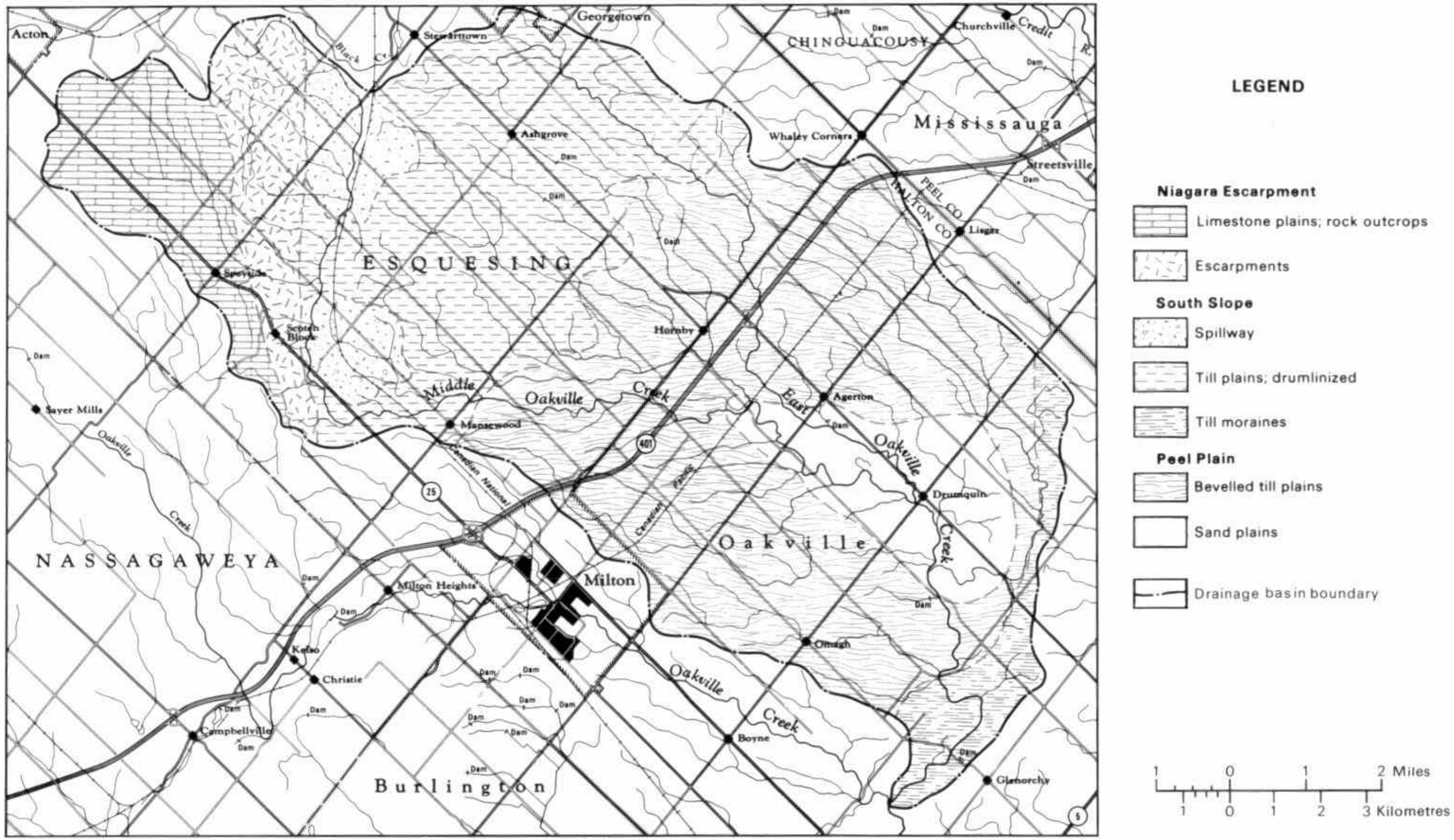


Figure 2. Physiographic divisions of the East and Middle Oakville creeks drainage basin (modified from Chapman and Putnam,1972).

GEOGRAPHY

LOCATION

The East and Middle Oakville creeks drainage basin is located in south-central Ontario in the County of Halton between 43° 28' and 43° 38' latitude and 79° 44' and 80° 02' longitude. The area is covered by the National Topographic Series sheets 30M/5, 30M/12 and 30P/9. Figure 1 shows the location of the drainage basin with respect to southern Ontario. The nearest population centres are Milton to the west of the basin and Georgetown to the north.

Access to the area is available via highways 401, 25 and a grid of township and county roads. Both the Canadian National and the Canadian Pacific railroads traverse the area.

PHYSIOGRAPHY

The East and Middle Oakville creeks drainage basin overlaps three physiographic regions, the Niagara Escarpment, the South Slope and the Peel Plain, as delineated by Chapman and Putman (1966). The areal distribution of these physiographic regions within the basin area are shown in Figure 2.

Niagara Escarpment

The Niagara Escarpment, unique to southern Ontario and to western New York State, comprises the northwestern portion of the drainage basin. The Escarpment is characterized by a sharp topographic break, formed by cliffs of erosion-resistant Silurian dolostone overlying softer Ordovician shale. In the study area, the Escarpment is veneered by hummocky accumulations of ground moraine and outwash deposits. Dolostone is quarried locally, exposing fresh sections of the bedrock units for examination.

South Slope

The South Slope physiographic region is divided by the Peel Plain into a northern portion, draping the base of the Escarpment and a southern portion comprising the Trafalgar Moraine and adjacent till plain. The northern portion is a drumlinized area of ground moraine and outwash deposits. The Trafalgar Moraine in the southern portion is a low ridge with an approximate relief of 20-25 feet formed during the retreat of the Lake Ontario ice lobe.

Peel Plain

The Peel Plain physiographic region, situated in the central portion of the basin, is characterized by an area of clay soils of low relief. Topographic irregularities have been obscurred by a blanket of glaciolacustrine sediments. These sediments were deposited in a shallow, short-lived glacial lake known as the "Peel Ponding".

DRAINAGE

The East and Middle Oakville creeks drainage basin is approximately 79 square miles in area. Both creeks rise in the bedrock plain just west of the scarp area and descend the Escarpment through narrow bedrock cuts. The creeks cut the South Slope through shallow overburden valleys, the relief being amplified by the rolling nature of the topography. The creeks merge south of Hornby. In the vicinity of Drumquin the combined creeks are incised into the bedrock, creating a 25 to 50-foot deep, narrow, steep-sided valley. The creek joins the main Oakville Creek in a deep valley southwest of Glenorchy.

The stream gradient varies over the basin, from approximately 70 feet per mile in the Escarpment area (between the 1000 to 800-foot contours) to 32 feet per mile in the South Slope area (between the 800 to 700-foot contours) to 16 feet per mile in the Peel Plain (between the 700 to 445-foot contours).

CLIMATE

The drainage basin lies within the South Slope and Huron Slope climatic regions (Figure 3) as delineated by the Ontario Department of Agriculture and Food (1966). The observed temperature and precipitation data for the Speyside IHD and Hornby IHD meteorological stations are presented in Tables 1a and 1b. The Hornby station is in the South Slope climatic region and the Speyside station is in the Huron Slopes climatic region.

Mean annual precipitation (1969-1974) for the Speyside station is 36.13 inches, while that for the Hornby station is 33.17 inches. The mean annual temperature for the Speyside station (1969-1974) is 43.1^{o}F, with a mean maximum temperature of 52.7^{o}F and a mean minimum temperature of 32.7^{o}F. The mean annual temperature for the Hornby station (1969-1974) is 44.8^{o}F, with a mean maximum temperature of 54.0^{0}F and a mean minimum temperature of 35.6^{o}F. These data indicate that the area above the Escarpment is for the most part both "wetter" and "cooler" than that below the Escarpment.

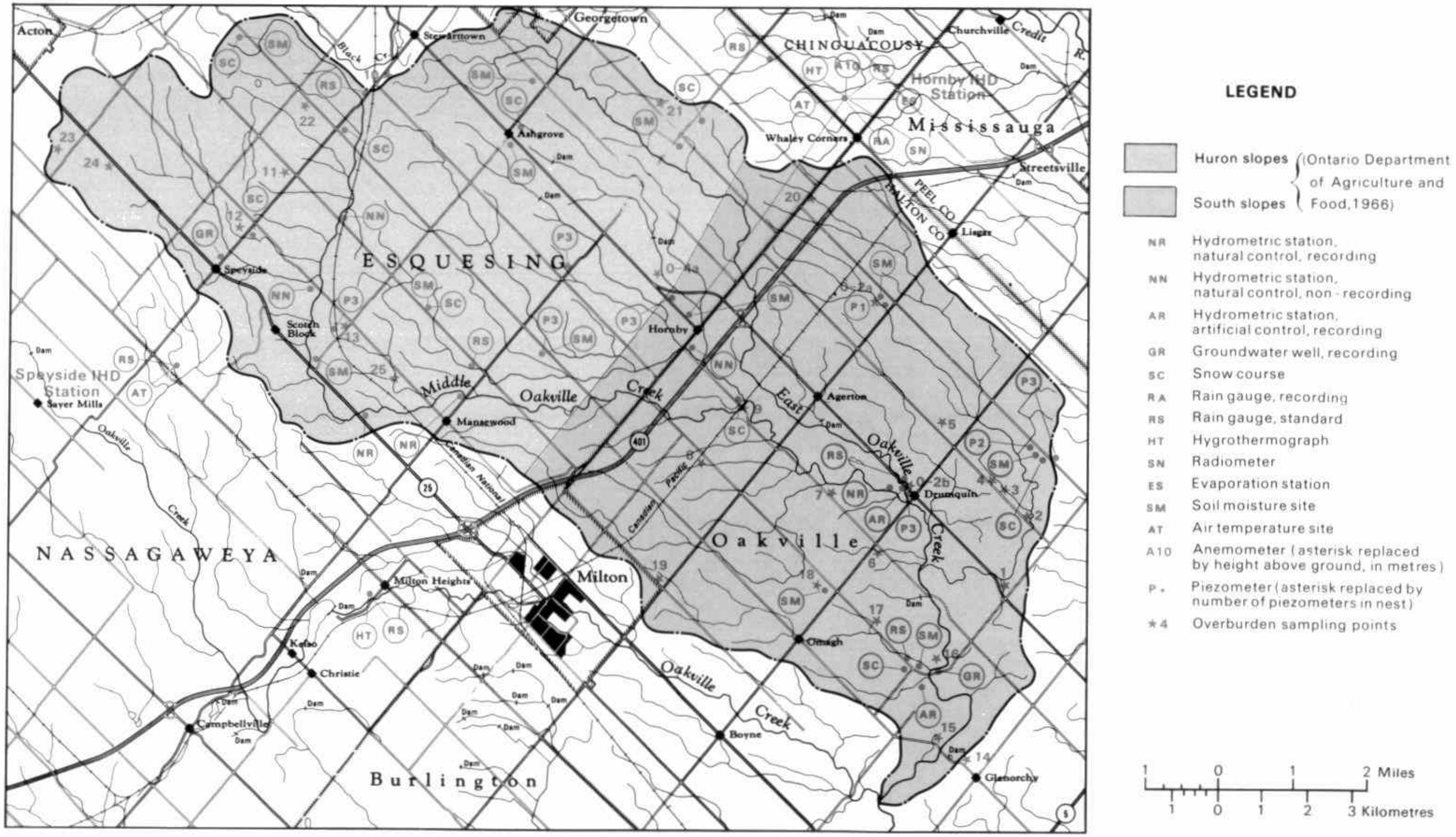


Figure 3. Climatic regions, instrumentation and overburden sampling points in the East and Middle Oakville creeks drainage basin.

TABLE 1a. OBSERVED TEMPERATURE AND PRECIPITATION FOR THE SPEYSIDE IHD METEOROLOGICAL STATION

		Jan.	Feb.	Mar.	April	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Ave./ Total PPT.
1969	mean max. temp.	28.0	29.6	34.7	53.9	64.5	70.9	79.0	80.4	69.3	55.5	43.0	27.1	53.0
	mean min. temp.	11.4	12.0	17.1	32.6	40.5	49.3	53.9	54.3	46.7	37.1	30.9	13.9	33.3
	mean temp.	19.7	20.8	25.9	43.2	52.5	60.1	66.4	67.4	58.0	46.3	37.0	20.5	43.1
	precipitation	1.49	0.28	1.68	4.21	3.45	1.60	3.95	3.79	0.51	3.21	3.27	2.60	30.04
1970	mean max. temp.	21.1	27.6	33.4	53.7	65.1	74.0	78.9	78.0	68.2	58.0	44.0	28.6	52.5
	mean min. temp.	5.4	8.0	16.6	32.6	43.6	50.3	55.9	52.7	48.7	41.1	31.5	14.8	33.4
	mean temp.	13.3	17.8	25.0	43.2	54.4	62.1	67.4	65.3	58.4	49.6	37.8	21.7	43.0
	precipitation	1.65	1.41	1.93	3.76	2.17	1.85	6.18	2.71	5.26	3.69	2.30	4.38	37.29
1971	mean max. temp.	22.4*	28.4	32.1	49.3	65.0	76.1	76.8	77.0	71.2	64.0	42.5	35.9	53.4
	mean min. temp.	4.3	14.1	15.5	28.0	38.4	51.5	52.5	51.0	51.0	44.3	28.6	20.7	33.3
	mean temp.	13.4	21.2	23.8	38.7	51.7	63.8	64.7	64.0	61.0	54.2	35.6	28.3	43.4
	precipitation	2.63	3.51	1.90	1.28	1.17	3.66	3.04	3.95	2.31	2.11	1.95	4.87	32.38
1972	mean max. temp.	28.0	26.1	31.7	45.9	67.7	69.5	72.6	75.9	67.2	51.5	37.6	32.0	50.5
	mean min. temp.	10.1	6.1	14.2	26.6	43.0	49.3	49.9	53.8	48.3	33.4	26.0	18.9	31.6
	mean temp.	19.1	16.1	23.0	36.3	55.4	59.4	61.3	64.9	58.8	42.5	31.8	25.5	41.2
	precipitation	3.02	2.01	4.71	2.46	2.81	4.30	4.12	3.64	3.14	4.04	2.51	3.10	39.86
1973	mean max. temp	29.0	26.6	44.2	51.5	59.5	75.1	80.0	79.2*	71.1	60.3	42.7	29.9	54.1
	mean min. temp.	15.9	7.8	28.3	33.8	41.7	53.4	54.7	57.4	44.3	39.7	31.7	17.4	35.5
	mean temp.	22.5	17.2	36.3	42.7	50.6	64.3	67.4	68.3	57.7	50.0	37.2	23.7	44.8
	precipitation	1.77	2.98	5.89	2.14	3.51	2.06	3.07	2.25	1.84	5.91	4.31	3.95	39.68
1974	mean max. temp.	28.3	25.1	35.5*	54.7	60.1	72.6	79.4	78.6	66.7	55.3	42.0	33.2	52.6
	mean min. temp.	11.4	6.8	21.4	33.1	39.1	49.9	53.7	52.8	42.9	32.7	30.6	22.5	29.5
	mean temp.	19.9	16.0	28.5	43.9	49.6	61.3	66.6	65.7	54.8	44.0	36.3	27.9	42.9
	precipitation	3.78	2.67	2.76	3.82	6.88	4.12	1.27	2.06	2.34	1.03	4.44	2.35	37.52
Monthly Average (1969-74)														
	mean max. temp.	26.1	27.2	35.3	51.5	63.6	73.0	77.8	78.2	68.9	57.4	42.0	31.1	52.7
	mean min. temp.	9.7	9.2	18.8	31.1	41.0	50.6	53.4	53.7	47.0	38.0	30.9	18.0	32.7
	mean temp.	18.0	18.2	27.1	41.3	52.4	61.8	65.6	56.9	58.1	47.8	35.9	24.6	43.1
	precipitation	2.39	2.14	3.15	2.94	3.33	2.93	3.60	3.07	2.57	3.33	3.13	3.54	36.13

* estimated temperature in ^{o}F precipitation in inches

TABLE 1b. OBSERVED TEMPERATURE AND PRECIPITATION FOR THE HORNBY IHD METEOROLOGICAL STATION

		Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly Avg./ Total PPT.
1969	mean max. temp	28.9	30.5	36.0	54.9	65.0	72.2	80.4	82.2	71.0	56.9	44.3	28.2	54.2
	mean min. temp.	13.6	15.9	20.6	34.2	41.6	50.3	56.5	58.0	49.5	38.7	31.7	15.0	35.2
	mean temp.	21.3	23.2	28.3	44.6	53.3	61.3	68.4	70.1	60.3	47.8	38.0	21.6	44.8
	precipitation	3.77	0.40	1.64	3.74	3.25	1.38	4.45	6.25	0.61	2.76	3.00	2.33	33.58
1970	mean max. temp.	22.5	29.3	35.8	55.0	65.3	74.8	80.5	80.8	69.9	59.0	45.5	29.5	54.0
	mean min. temp.	4.5	12.1	20.0	33.8	43.8	52.4	59.0	56.5	51.2	43.0	33.0	16.1	35.4
	mean temp.	13.5	20.7	27.9	44.4	54.6	63.6	69.8	68.7	60.6	51.0	39.3	22.8	44.7
	precipitation	1.57	0.89	1.86	3.80	2.45	2.11	2.95	3.56	3.15	3.32	2.02	3.62	31.30
1971	mean max. temp.	23.4	29.8	33.3	51.0	65.8	76.4	78.3	78.3	72.9	65.1	44.4*	37.2	54.6
	mean min temp.	6.6	16.2	19.0	30.6	40.9	53.5	55.5	55.2	53.3	46.1	30.1	22.6	35.8
	mean temp.	15.0	23.0	21.2	40.8	53.4	65.0	66.9	66.8	63.1	55.6	37.3	29.9	44.8
	precipitation	2.48	4.0	2.01	1.18	1.26	3.16	3.01	4.15	1.27	1.49	1.55	4.45	30.01
1972	mean max. temp.	29.7	27.5	31.7	47.1	68.7	70.7	79.3	76.0	71.0	52.6	39.6	33.0	52.2
	mean min. temp.	12.4	9.2	18.3	28.7	43.6	50.8	57.1	56.0	50.1	34.9	28.4	21.6	34.3
	mean temp.	21.1	18.4	25.0	37.9	56.2	60.8	68.2	66.0	60.6	43.8	34.0	27.3	43.3
	precipitation	1.84	1.89	4.40	2.53	2.67	4.59	3.43	3.77	3.07	3.88	2.59	4.05	38.71
1973	mean max. temp.	31.1	27.5	45.1	53.3	60.6	76.0	81.1	82.0	72.3	61.2	44.7	30.6	55.4
	mean min. temp.	18.2	9.7	29.9	34.6	42.8	55.3	57.9	60.2	48.0	41.8	32.6	18.4	37.4
	mean temp.	24.7	18.6	37.5	44.0	51.7	65.7	69.5	71.1	60.2	51.5	38.7	24.5	46.5
	precipitation	0.77	2.20	5.11	2.02	3.17	2.28	1.65	2.27	1.98	4.97	3.94	2.87	33.23
1974	mean max. temp.	29.1	26.3	37.3	56.0	61.2	72.8	80.0	79.8	68.5	56.7	43.9	34.9	53.9
	mean min. temp.	13.8	10.1	24.4	34.6	40.4	51.7	57.0	56.0	46.1	34.2	32.2	24.8	35.4
	mean temp.	21.5	18.2	30.9	45.3	50.8	62.3	68.5	67.9	57.3	45.2	38.1	29.9	44.7
	precipitation	2.42	1.83	2.45	3.45	6.68	5.17	1.16	1.22	1.84	0.77	3.44	1.77	32.20
Monthly Average (1969-74)														
	mean max. temp.	27.4	28.5	36.5	52.9	64.4	73.8	79.9	79.8	70.9	58.6	43.7	32.2	54.0
	mean min. temp.	11.5	12.2	22.0	32.7	42.2	52.3	57.2	57.0	49.7	39.8	31.3	21.7	35.6
	mean temp.	19.5	20.3	28.5	42.8	53.3	63.1	68.5	68.4	60.3	49.1	37.5	26.0	44.8
	precipitation	2.14	1.87	2.91	2.79	3.25	3.11	2.77	3.54	1.99	2.86	2.76	3.18	33.17

* estimated temperature in °F precipitation in inches

GEOLOGY

BEDROCK GEOLOGY

The bedrock stratigraphy for the basin, as presented in Bolton (1957), Cowell and Woerns (1975), and Telford, Bond and Liberty (1974), and interpreted from field investigations, is presented in Table 2, while the areal distribution of the bedrock units is illustrated in Map 1. The bedrock ranges in age from Upper Ordovician to Middle Silurian. The oldest unit, the Queenston Formation of the Upper Ordovician, is exposed below the Escarpment along the combined East and Middle Oakville creeks, near Drumquin.

The Silurian formations are exposed along the Escarpment in quarries and outcrops. The local stratigraphic interpretation of the Silurian is complicated by facies changes; the Silurian units being lithologically and paleontologically distinct from the type sections of the units which are considered to be their equivalents in the Niagara and Bruce Peninsula areas. The stratigraphy of the Silurian units in the Niagara Peninsula, that over the Algonquin Arch (a low structural ridge separating the depositional areas of the Michigan and Appalachian basins during the early Paleozoic Era) and that in the Bruce Peninsula are compared in Table 3.

Upper Ordovician

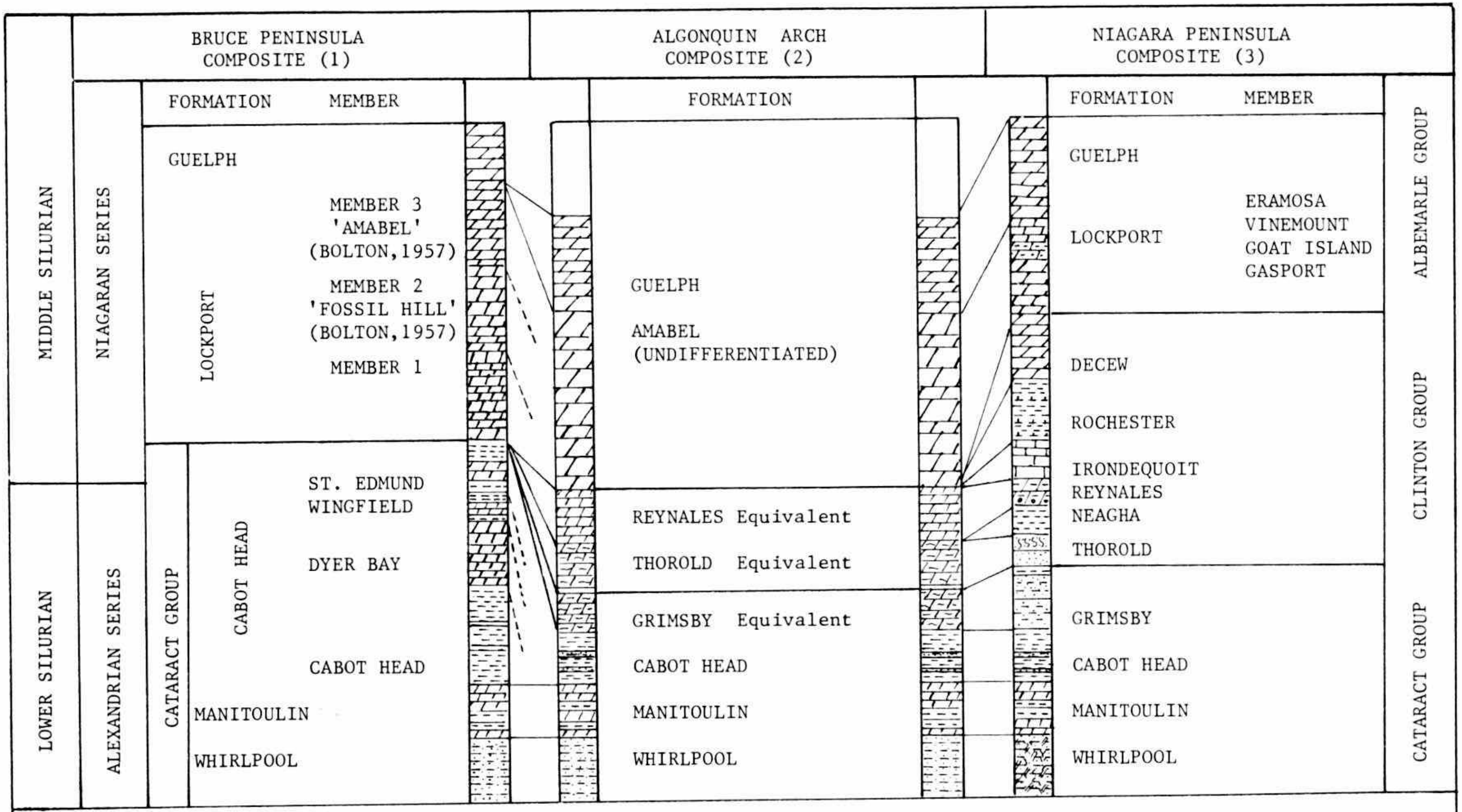
The Upper Ordovician, represented by the Queenston Formation is traceable along the base of the Escarpment from New York State to the Cabot Head area of the Bruce Peninsula. The type section of this unit is at Queenston, Ontario.

The Queenston Formation has a distinctive, uniform, brick-red to mottled-green colouring. This Formation, near Drumquin, is a thinly bedded shale, arenaceous to argillaceous in texture. Greenish oxidation zones are present along bedding planes and vertical fractures. The contact between the Queenston Formation and the overlying Halton Till is, in places, almost gradational because of both the strong weathering of the shale and the inclusion of shale fragments in the till.

Grabau (1913) suggested that the source area of the Queenston Formation was the Appalachian region with deposition taking place in a deltaic estuarine environment.

UPPER ORDOVICIAN	ALEXANDRIAN SERIES (LOWER SILURIAN)	NIAGARAN SERIES (MIDDLE SILURIAN)		
QUEENSTON FORMATION	CATARACT GROUP	CLINTON GROUP LOWER → UPPER	ALBERMARLE GROUP	
	WHIRLPOOL MANITOULIN CABOT HEAD GRIMSBY (Equivalent)	THOROLD? REYNALES IRONDEQUOIT (Equivalent)	AMABEL	FORMATION
		Transition between Reynales and Fossil Hill just to north	COLPOY BAY WIARTON (Reef like)	MEMBER

TABLE 2. BEDROCK STRATIGRAPHY IN THE VICINITY OF THE EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN (AFTER DETAILED SECTIONS FROM BOLTON)



(1) Liberty and Bolton, 1971; (2) Telford, Bond and Liberty, 1974 and Cowell and Woerns, 1975;
(3) Liberty, Feenstra and Telford, 1976.

TABLE 3. STRATIGRAPHIC INTERPRETATION OF THE LOWER AND MIDDLE SILURIAN (MODIFIED FROM COWELL AND WOERNS, 1975)

Lower Silurian

The Lower Silurian is represented by the Cataract Group. This Group, as defined by Bolton and Liberty (1955) and Liberty and Bolton (1956), includes the following formations:

NIAGARA FALLS TO STONEY CREEK	STONEY CREEK TO CLAPPISON CORNERS	CLAPPISON CORNERS NORTHWARDS
Grimsby Formation	Grimsby Formation	Cabot Head Formation
	Cabot Head Formation	
Power Glen Formation		Manitoulin Formation
	Manitoulin Formation	
Whirlpool Formation	Whirlpool Formation	Whirlpool Formation

after Bolton (1957, p.9)

The Whirlpool Formation, a quartzose sandstone, is traceable from New York State northward along the Escarpment to Duntroon (8 miles south of Collingwood). Locally, the Whirlpool Formation outcrops in the vicinity of Speyside. At this location the Whirlpool Formation is represented by a blue to reddish, medium-grained, well-sorted sandstone. The unit is characteristically unfossiliferous and has an average thickness of 12 feet between Milton Heights and Credit Forks (Caley, 1940). Bolton (1957) suggested that the Whirlpool Formation was deposited in transgressing shallow seas along the Queenston shelf, as a marginal deposit.

The Manitoulin Formation, which overlies the Whirlpool Formation conformably, is a thin to medium-bedded, grey crystalline dolostone. Calcite vugs, pyrite, chert nodules and shale partings (interbeds) are common. This unit is estimated to be approximately 15-20 feet thick, locally. Bryozoan and brachiopod fossils are common on outcrop surfaces. The type section is on Manitoulin Island (Bolton, 1957). The Manitoulin Formation is assumed to have been deposited in a shallow, warm, well-aerated sea (Bolton, 1957; after Eller, 1942). The clastic component near the top of the Manitoulin would indicate a regressive sea.

The Cabot Head Formation can be viewed in the Dufferin Materials & Construction Co. Ltd. quarry, located on lots 9 and 10, Concession 1, Esquesing Township. At this location, the Formation is represented by a greenish-grey, massive shale, interbedded with thin siltstone beds. The upper beds are considered to be the facies equivalents of the Grimsby Formation and the Thorold Formation of the Niagara Peninsula (after Telford, Bond and Liberty, 1974). A 60-foot section of this unit is exposed in the quarry. The lower contact with the Manitoulin Formation is gradational, while the upper contact with the Reynales and Amabel formations is well-defined. Bolton (1957) proposed a shallow marine, depositional environment for the Cabot Head Formation, which was subject to rapid changes in sedimentation.

Middle Silurian

The Middle Silurian is represented in the study area by the Reynales and the Amabel formations. The Reynales Formation outcrops in the vicinity of Speyside and is exposed in the Dufferin Quarry. Telford, Bond and Liberty (1974) divided the Reynales into two lithologically differing upper and lower parts. The lower part is a blue-grey, thin to medium-bedded, dense, dolostone with abundant bioclastic material (especially crinoidal and brachiopod fauna). The upper part is characteristically a dense dolostone, more uniformly bedded and less fossiliferous. The upper part may be equivalent to the Irondequoit Formation. Both the lower and upper parts are argillaceous and contain interbeds of shale. Approximately 6 feet of the Reynales Formation is exposed in the Dufferin Quarry. Deposition was considered by Bolton (1957) to be in the Lower Clinton sea followed by an erosional period marked by the disconformity between the Reynales and overlying Amabel Formation.

The Amabel Formation has not been subdivided in the vicinity of the basin because of the difficulties of interpreting the stratigraphy. In this area the lithology appears to be transitional between that of the Colpoy Bay and Wiarton members of the Amabel Formation of the Bruce Peninsula and the Gasport Member of the Lockport Formation of the Niagara Peninsula (Telford, Bond and Liberty, 1974). The Amabel Formation can be viewed in the Dufferin Quarry (Photo 1). At this location, the Amabel Formation is a highly fossiliferous blue-grey, dense, crystalline dolostone. Vugs and solution cavities are common; some of these were measured to be 2 to 4 feet high and 15 to 25 feet long. Reef structures, lenticular in shape, are also abundant. The upper 25 feet of this unit is highly fractured and weathered. These strata are typical of stable shelf environments, with their characteristic continuous sedimentation. (Bolton, 1957).

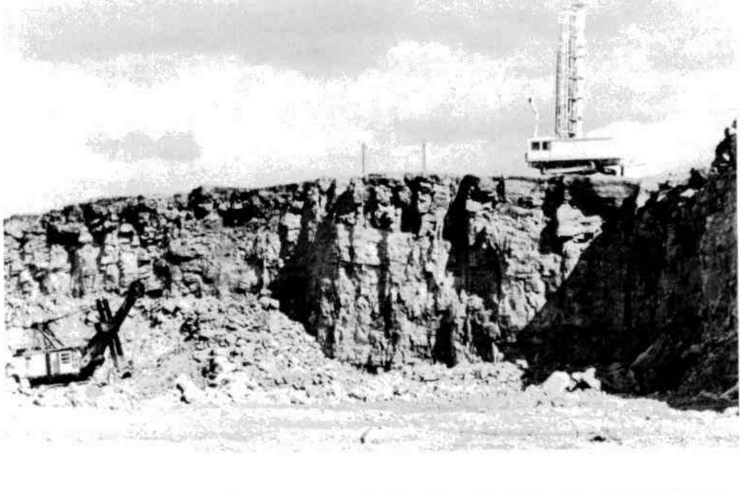


Photo 1. Amabel Formation exposed in the Dufferin Materials & Construction Co. Ltd. quarry.

BEDROCK TOPOGRAPHY AND STRUCTURE

The bedrock surface, as contoured from water-well geologic logs and a geophysical seismic survey conducted by the MOE, (1975), is presented on Map 1. The bedrock surface has an elevation change of approximately 675 feet, with a maximum recorded elevation of 1,198 feet above mean sea level in the northwestern portion of the basin above the Escarpment, to a low at 522 feet above mean sea level in the southeast. According to Liberty (1969), the present attitudes of the Paleozoic strata are essentially those of their initial depositional dip, variation in dip direction being the result of structural control during deposition. The regional inclination varies from 20 feet per mile in the southwest to 30 feet per mile in the north.

SURFICIAL GEOLOGY

The lithology, areal distribution and mode of origin of the overburden deposits (glacial, glaciofluvial and glaciolacustrine) are presented in Map 2. The overburden (isopach) thickness of these unconsolidated sediments is presented in Map 3. All overburden is of Pleistocene and Recent age.

The Pleistocene sediments are present throughout the basin as stratified and unstratified deposits of glacial origin. The Recent sediments occur locally as alluvium and muck.

Overburden thickness as based on water-well records, ranges from 0-35 feet (average ≃ 10 feet) above the Escarpment, to 8-135 feet (average ≃ 40 feet) below the Escarpment. The thickest deposits (up to 135 feet) occur at the base of the Escarpment.

Geomorphic Features

There are several geomorphic features in the East and Middle Oakville creeks drainage basin which are associated with depositional and erosional forces active during the Late Wisconsinan Stage. These features are: till plains, drumlins, outwash plains, the Trafalgar Moraine, and the Lake Peel Plain. Postglaciation features include river valleys and local bog and muck accumulations.

Till Plains - Two such areas occur in the basin, the Wentworth Till plain and the Halton Till plain, named after the predominant till units present in the area (Karrow, 1963).

The Wentworth Till plain is a relatively flat area west of the Niagara Escarpment. It consists of a thin sheet of sandy and stoney till with numerous pockets of sand and gravel. The till sheet ranges in thickness from 0-35 feet within the basin. Glacial erratics of both dolostone and Precambrian rock types are common.

The Halton Till plain, located east of the Escarpment, is a gently undulating to rolling area consisting of silty to clay till and interbedded sand and gravel deposits. The overburden thickness in this area ranges from a few feet to over a 100 feet. In the central portion of the basin the till plain is veneered by thin glaciolacustrine deposits.

Drumlins - Drumlins and drumlinoids features are present just north of Hornby in the Halton Till plain. The largest of these low lying elongated hills is about a mile in length and rises about 50 feet above the surrounding area. The major axes are oriented at approximately N130°E. Based on the water-well records of wells finished in these drumlins, the drumlin cores are till.

Outwash Plain - Extensive outwash deposits are present along the base of the Escarpment. The silt, sand and gravel materials were deposited between the receding glacial ice sheet and the Escarpment by meltwater. The areal extent of these deposits is outlined on Map 4. Along the base of the Escarpment, the Middle Oakville Creek has partially eroded the outwash deposits and in places obscured them with alluvial materials. Overburden thicknesses of up to 131 feet have been recorded for water wells finished in this area (just southeast of Speyside).

Trafalgar Moraine - Karrow (1963) identified the Trafalgar Moraine as the youngest moraine in the Hamilton-Galt area. This low-lying moraine, composed of silty Halton Till, represents a brief halt in the recession of the Lake Ontario ice sheet. Up to 70 feet of till have been encountered in water wells finished in the Moraine.

Present drainage appears to have been influenced by this Moraine as the combined East and Middle Oakville creeks run parallel to the moraine for about two miles before cutting through the Moraine.

Lake Peel Plain - Glaciolacustrine sediments, relating to a brief stand of water referred to as the Lake Peel Ponding, are found just to the northwest of the Trafalgar Moraine. This ponding, as indicated by the limited thickness of the glaciolacustrine deposits, was short lived. The lake drained following the retreat of the ice front from the vicinity of the Trafalgar Moraine.

The deposits consist of clay, silt and fine sand lenses ranging in thickness from a few inches to eight feet. Chapman and Putnam (1966) measured up to 10 feet of varved clays in a road cut along the Seventh Line Road in Oakville near Drumquin. Varves present along stream erosion cuts in the same area are thin, suggesting deposition in quiet water.

The contact between the Halton Till and these glaciolacustrine sediments is poorly defined, and in places, appears to be gradational in character. Where the creeks dissect the plain, the sediments are often obscured by local deposits of alluvium. The areal extent of these deposits is presented on Map 2.

Mechanical and Carbonate Analyses

Mechanical and carbonate analyses were conducted on overburden samples collected in the field and from split spoon samples collected during the installation of the observation wells. Table 4 presents the results of these analyses; Figure 3 shows the locations of the samples and Figure 4 presents the mechanical analyses in graphic form.

TABLE 4. MECHANICAL AND CARBONATE ANALYSES FOR SAMPLES COLLECTED IN THE BASIN

	MECHANICAL %			CARBONATE %			
Sample No. or Location	Gravel & Sand	SILT	CLAY	CALC.	DOL.	TOTAL	RATIO
WENTWORTH TILL (?) ABOVE ESCARPMENT							
23	48.6	41.7	9.7	2.6	31.8	34.4	0.1
24	35	48	17	0.1	1.5	1.6	0.1
WENTWORTH TILL-HALTON TILL CONTACT ALONG EDGE OF ESCARPMENT							
12	16	49	35	0.1	2.4	2.5	0.1
22	5	59	36	1.2	6.4	7.6	0.2
HALTON TILL							
1	24	44	32	0.5	1.6	2.1	0.3
2	16	67	17	0.4	1.4	1.8	0.3
5	45	38	17	0.1	1.8	1.9	0.1
6	14	52	34	0.0	1.2	1.2	-
8	12	51	37	0.5	1.4	1.9	0.4
0.2a 10' SS* (A)	33.2	53.4	13.4	9.0	3.0	12.0	3.0
20' SS (B)	58.5	31.5	10.0	21.0	5.0	26.0	4.2
35' SS (C)	36.8	42.9	20.3	22.0	6.0	28.0	3.7
0-2b 5' SS (D)	30.9	43.7	25.4	13.0	3.0	16.0	4.3
10' SS (E)	32.0	53.4	14.6	10.0	3.0	13.0	3.3
30' SS (F)	49.1	44.1	6.8	17.0	9.0	26.0	1.9
0-4a 5-6' SS (G)	46.8	36.6	16.6	5.0	4.0	9.0	1.2
11' SS (H)	36.2	41.4	22.4	7.0	4.0	11.0	1.7
50' SS (I)	35.2	45.6	19.2	12.0	5.0	17.0	2.4
14	20	41	39	0.0	0.0	0.0	-
15	11.3	52.8	35.9	11.9	3.3	15.2	3.6
16	14.7	37	48	0.0	2.0	2.0	-
17	19	45	36	15.0	4.5	19.5	3.3
18	12.4	38.6	49	0.2	1.1	1.3	0.2
19	14	42	44	0.0	1.2	1.2	-
20	25	42	33	0.4	3.4	3.8	0.1
21	27	37.5	35.5	0.0	1.6	1.6	-
25	5	51	44	0.0	0.8	0.8	-
LAKE PEEL DEPOSIT							
3	68	26	6	0.1	1.6	1.7	0.1
4	90	10	-	0.1	1.4	1.5	0.1
7	65	31	4	0.4	1.2	1.6	0.3
RECENT ALLUVIUM							
9	2	34	64	27.9	3.8	31.7	7.3
OUTWASH DEPOSIT							
10	48	49	3	15.6	3.9	19.5	4.0
11	45	54.5	0.5	19.1	5.6	24.7	3.4
13	94	6	-	15.2	6.6	21.8	2.3
0-4a 10' SS (J)	100	-	-	11.0	6.0	17.0	1.8
31' SS (K)	87.6	12.4	-	10.0	7.0	17.0	1.4
48' SS (L)	67.2	30.3	2.5	11.0	7.0	18.0	1.6

*SS - split spoon sample

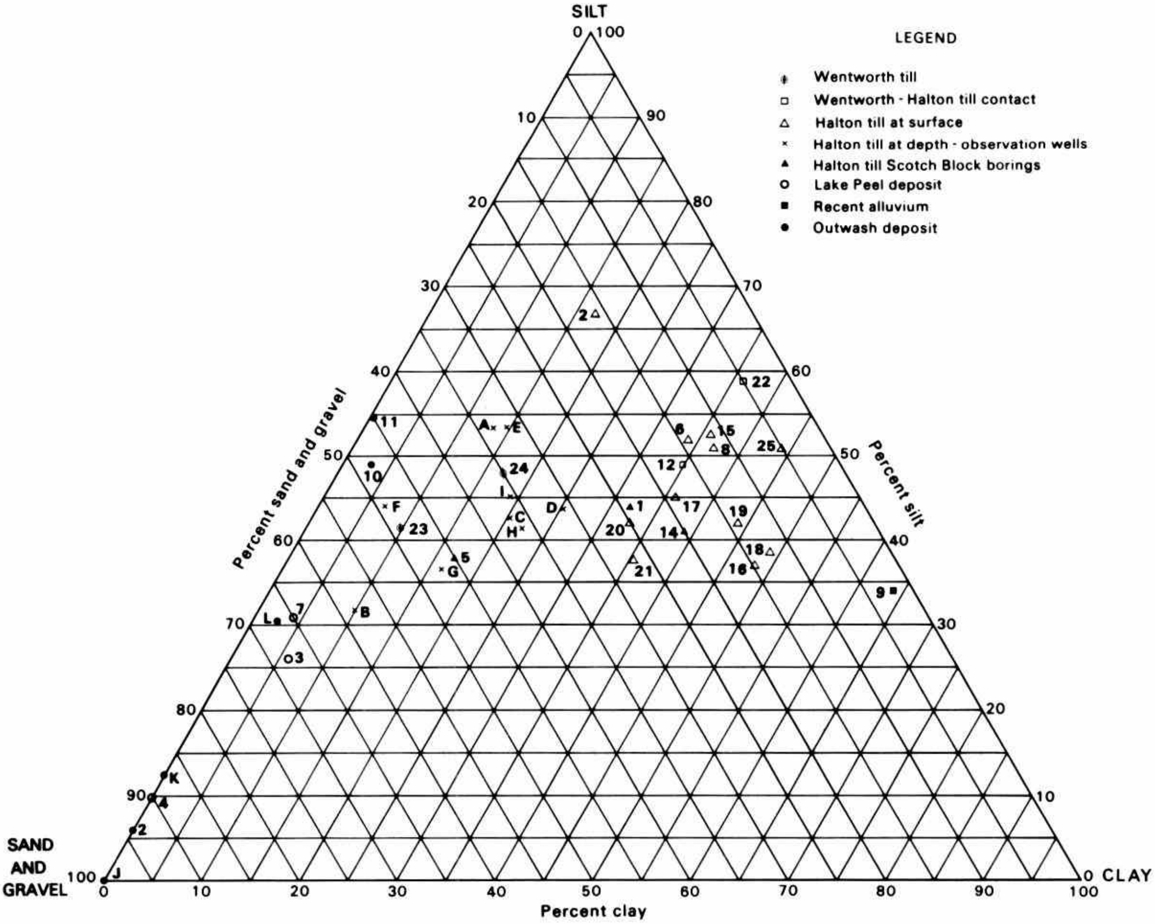


Figure 4. Mechanical analyses presented on graphic plot.

Stratigraphic Interpretation of the Overburden

Above the Escarpment - The overburden above the Escarpment consists of a single discontinuous unit. This unit ranges from a sandy till in the west, to a silty-clay till near the top of the Escarpment. Local accumulations of sand and gravel are common. Karrow (1963, 1974) called the sandy till the Wentworth Till, and considered this till as being older than the Halton Till to the east.

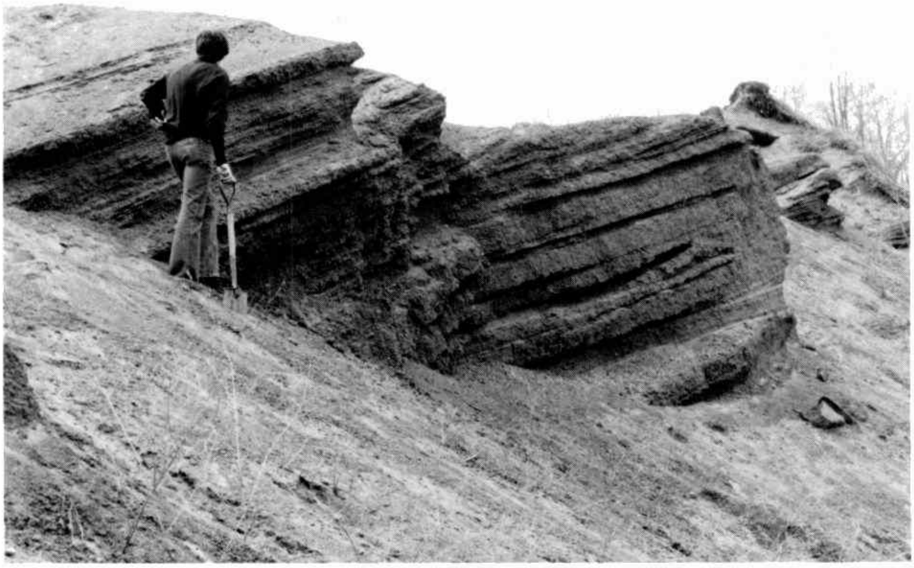
The contact between the Wentworth and Halton tills in the area was not definable and no stratigraphic relationship could be established. Two till samples (Samples #12 and 22), collected near the top of the Escarpment, were similar in texture to that of the Halton Till samples collected below the Escarpment. It is therefore felt, that the contact may be gradational, the Wentworth and Halton tills being facies of the same till sheet.

Below the Escarpment - The stratigraphic sequence inferred from MOE observation-well logs, the logs for deep borings in the Scotch Block Reservoir area (E. M. Peto Associates Ltd. 1967) and field investigations for the area below the Escarpment is presented in Table 5. The MOE observation-well logs are presented in Appendix 1.

TABLE 5. OVERBURDEN STRATIGRAPHY

STAGE	UNIT OR EVENT	LITHOLOGY
Recent	Alluvium and marsh deposits	gravel, sand, silt, clay and muck
Late	Lake Peel Ponding	gravel, sand, silt, clay
Wisconsinan	Glacial Unit (Halton Till)	sandy to clayey till
	Outwash Deposits	gravel, sand, silt clay
	Glacial Unit (Halton-Wentworth Till)	silty till
Age has not been established	Channel sands	gravel, sand

The overburden in this area consists of a sequence of interbedded glacial (Halton-Wentworth Till) and glaciofluvial deposits (outwash) which overlie the Queenston Formation. The till ranges in texture from sandy to clayey and in colour from brown to red. Both the colour and texture of the till are related to the proximity of the till to the bedrock, becoming darker and "heavier" closer to the bedrock. A silty sand till is identified in the deeper borings in the Scotch Block Reservoir area (E. M. Peto Associates Ltd., 1967). This till may be the Wentworth Till, but the stratigraphic relationship is poorly defined. Where the Halton-Wentworth Till - Queenston Formation contact is exposed, the till can be seen to grade into undisturbed beds of shale. The till is noticeably sandier and is locally stratified in the vicinity of the Escarpment. The till sheet ranges in thickness from a few feet near the lower reaches of the basin, to more than 60 feet at the base of the Escarpment.



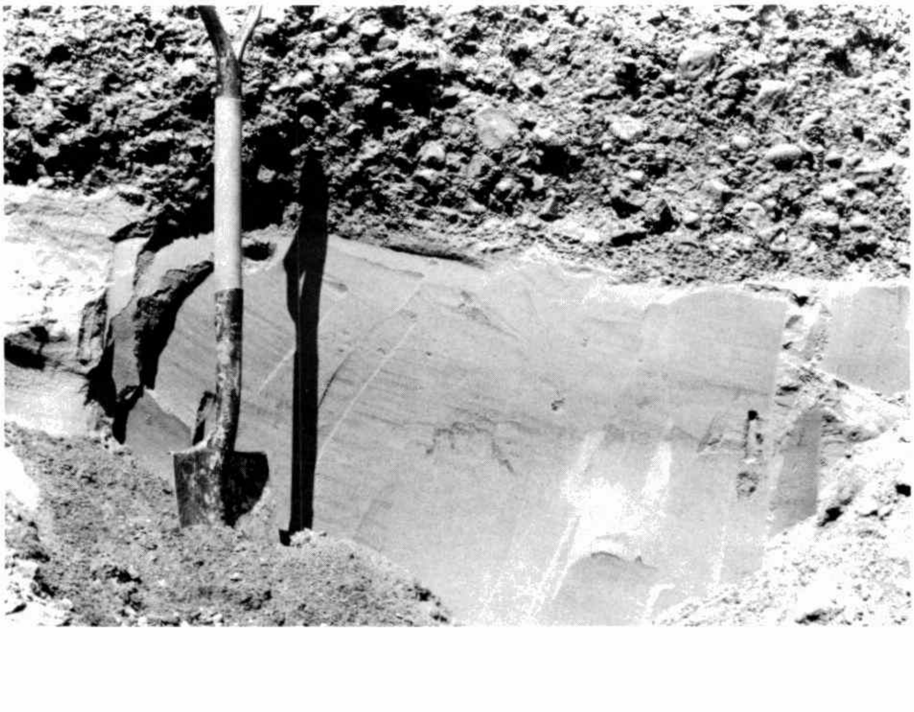


Photo 2 and 3 Outwash deposit along the base of the Escarpment.

Glaciofluvial deposits occur at depth under most of the basin between the Escarpment and Highway 401. The thicknesses range from less than a foot to over 130 feet near the Scotch Block Reservoir. The areal distribution and recorded thicknesses of these deposits are illustrated on Map 4. This map is based on data from domestic water-well logs finished within the basin.

The sand and gravel sediments appear to have been deposited under different circumstances and are separated into two units.

1) Channel sand and gravel. These coarse-grained sediments are confined to bedrock lows and channels. The major deposit centers on Hornby, and several other minor deposits found in bedrock channels south of Highway 401, are of this type.
2) Outwash sand and gravel. The outwash sand and gravel deposits make up the bulk of the stratified clastic materials present in the area between the Escarpment and Highway 401. The texture ranges from well-sorted silt and fine sand (Photo 2) to poorly sorted sand and gravel (Photo 3). Internal structural features are common, these include graded and cross-bedding, slump structures and cut and fill features. The glaciofluvial materials at the base of the Escarpment mark a major spillway. The sand and gravel east of the spillway also appears to be of the same origin and represent a fanning out of the original spillway to the south with the continued retreat of the ice margin. A readvance of the glacier covered these glaciofluvial sediments with a layer of till.

GLACIAL HISTORY

Information on the glacial history of this part of southern Ontario is presented in Chapman and Putnam (1966), Cowell and Woerns (1975), Dreimanis and Karrow (1972) and Karrow (1963, 1968, 1974). There is no record of glacial or interglacial events in the study area which are identified as being dated earlier than the Port Huron Stadial of the Late Wisconsinan. Although, the buried channel deposits and some of the outwash sand and gravel deposits (underlying the till sheets) may be of earlier age based on their stratigraphic position, no conclusions can be drawn from this study.

The oldest identified unit in the Basin is the Wentworth Till, which outcrops above (west of) the Escarpment. Near the edge of the Escarpment the Wentworth Till appears to grade laterally into the Halton Till, the grain texture of the till sheet becoming higher in clay content. Till designation has been a problem in this area for some time, as is noted in Karrow (1969 and 1974). Both till sheets are related to the last major advance and retreat of the Lake Ontario ice lobe.

Concurrent with the retreat of the ice sheet from the area, was the deposition of the thick glaciofluvial sand and gravel deposits at the base of the Escarpment. The interfingering of these deposits with till suggests a fluctuating ice front. The Trafalgar Moraine near the southeastern portion of the basin, respresents a brief halt in the recession of the ice front. Glacial meltwaters ponded north of the Moraine resulting in the formation of the short-lived Lake Peel Ponding. This Lake drained following the retreat of the ice front from the vicinity of the Trafalgar Moraine. Recent deposition consists of muck and alluvium, laid down in low-lying areas and adjacent to the watercourses which dissect the basin.

GROUND WATER RESOURCES

BASIN INSTRUMENTATION

A number of meteorological and hydrometric stations were established in the East and Middle Oakville creeks drainage basin in order to provide data for the hydrologic evaluation. The hydrometric stations include streamflow gauges, observation wells and piezometer nests. The location, identification code and type of instrument are shown in Figure 3. The location of the water wells and observation wells used in the study are presented on Map 5.

HYDROGEOLOGIC UNITS

The hydrogeologic units in the drainage basin may be classified according to their hydraulic characteristics as either aquifers or aquitards. An aquifer is a water-bearing geologic unit such as a sand or gravel which has a potential for yielding water of usable quantity and quality. An aquitard is a water-bearing geologic unit which does not yield or transmit water readily. Clay and till are considered to be aquitards.

In bedrock, ground water occurs and is transmitted primarily in openings such as joints, fractures and solution cavities. The availability of water stored in these openings is dependent on the degree of interconnection of these openings and the number of openings encountered in the construction of a well. In unconsolidated sediments (overburden), ground water occurs and is transmitted in the intergranular pore spaces. The availability of this water is a function of the porosity and the ability of the material to transmit water (hydraulic conductivity). Clay, for example, is highly porous; however, it does not transmit water readily because water adheres to the grain particles rather than passes through them. Sand, on the other hand, has both a high porosity and hydraulic conductivity and freely transmits water.

The principal hydrogeologic units encountered in the study area are presented in Table 6.

TABLE 6. HYDROGEOLOGIC UNITS IN THE DRAINAGE BASIN

Hydrogeologic Unit	Water-Yielding Characteristics
Halton and Wentworth Tills	Aquitard, sand lenses may yield sufficient supplies to meet domestic requirements
Outwash and Channel Sand and Gravel Deposits	Aquifer, yield dependent on local permeability and thickness
Amabel Formation	Aquifer, yield dependent on degree of fracturing and available drawdown
Queenston Formation	Aquitard, upper 10-20 feet is often weathered and may provide sufficient supplies to meet domestic requirements

The Halton and Wentworth tills act as aquitards. Sand lenses are common, but are generally thin and limited in areal extent and may only sustain one or two domestic wells each. Where these tills confine coarse-grained materials such as outwash sand and gravel (Esquesing Township, Concession IX or X; lots 5 and 6), artesian conditions are often encountered in the outwash deposits below the tills.

The Outwash Sand and Gravel deposit, which extends along the base of the Escarpment from north of Georgetown southward to the Cedar Springs area, constitutes one of the major aquifers in this part of Ontario. Both Georgetown and Milton obtain their water supplies from thick sections of this aquifer. The ground water in this aquifer is under unconfined (water-table) conditions where the sand and gravel are exposed near the base of the Escarpment and under confined (artesian) conditions to the east, where the outwash materials pinch out in ancestral drainage channels below the till materials. This aquifer is adequate in meeting domestic water requirements. Any future use for industrial and municipal purposes would have to be established by aquifer evaluation tests. The areal distribution of these sand and gravel deposits is presented in Map 4.

The Amabel Formation, is one of the most important and productive rock aquifers in Ontario. Its use in the basin, however, is restricted by the proximity of the Escarpment. The Escarpment acts as a ground-water sink, lowering the water table immediately to the west of it. A well finished near the top of the Escarpment has a lower available drawdown then a similar well completed some distance from the Escarpment and will therefore have a lower sustained yield. This aquifer however, is generally adequate in meeting domestic water requirements.

The Queenston Formation generally acts as an aquitard with the exception of the upper 5-10 feet which are commonly weathered thus having a greater permeability. This zone will often sustain a domestic water well; however, the available drawdown and sustained yield will generally be small.

HYDRAULIC PROPERTIES OF THE BEDROCK AND OVERBURDEN

The hydraulic properties of the bedrock and overburden are expressed quantitatively by the coefficients of transmissibility (also referred to as transmissivity), permeability (hydraulic conductivity) and storage. These can be estimated for different hydrogeologic units by one or more of the following methods:

1. pumping and recovery tests,
2. estimation of transmissivity from specific-capacity values derived from short-term pumping test data, and
3. empirical relationship between grain-size distribution and permeability.

The values obtained by these methods can be used as a rough prediction of the quantity and availability of water from both specific hydrogeologic units and specific areas within the basin. For example, aquifers with similar physical characteristics and origin, will for the most part have similar hydraulic properties.

TABLE 7. AQUIFER EVALUATIONS BASED ON PUMPING AND RECOVERY TEST DATA FROM CONSULTANTS' REPORTS

Hydrogeologic Unit	Location	Source of Data	Well # where Available	Coefficient of			Comments
				Transmissibility IGPD/ft.	Permeability IGPD/ft^2	Storage	
Outwash Sand and Gravel	Hornby	Maple Leaf Mills Ltd. Kirk (1967)	1103	30,000	1000	10^{-3}	Aquifer-approx. 30' thick, sand and gravel
	Kelso	Milton Water Supply Dixon (1977)	TW 3/63	200,000	5000	10^{-2}-10^{-1}	Upper aquifer - 60' thick
				350,000	5800	10^{-3}	Lower aquifer - 40' thick, strong boundary condition
	Campbellville	Campbellville Gravel Supply Ltd. Kirk (1965)		55,000	500	10^{-4}	Aquifer, approx. 60-80' thick
	Georgetown	Georgetown Water Supply Bryck (1977)	PW 4	90,000*-150,000		10^{-5}	Maple Street well field - 60' thick, sand, gravel, silt. *Lower T following 2 hr. pump test.
			PW 5, 6	500,000		10^{-6}	Princess Anne well field - 55' thick, sand, gravel, silt
Amabel Formation	Acton	Acton Water Supply Dixon (1977)	IWS 1/56	13,000-73,000			Depth 62', well was grouted back because mineralized water was encountered at 176'
			IWS 2/57 and 3/57	79,000-100,000		10^{-4}-10^{-3}	Depth 46'
	Rockwood	Rockwood Water Supply Sobanski (1968)	TW1-67	4500-12,000		10^{-5}	Aquifer - 22.5'-195'
			TWS 2-67	1000-2900		10^{-5}	Aquifer - 15'-210'
	Campbellville	Mohawk Raceway Kirk (1965)		11,000-19,000		10^{-2}	Aquifer - 100' thick, under 5' overburden

Pumping and Recovery Tests

These tests, in which the effects of pumpage are measured in the pumped well and/or nearby observation wells, are used in arriving at reasonable estimates of the performance and efficiency of the pumped well and also the performance of the hydrogeologic unit in which the well is emplaced.

The transmissivity, and the coefficients of permeability and storage calculated for various pumping and recovery tests conducted on hydrogeologic units in the vicinity of the basin are presented in Table 7. These tests were conducted by consultants hired by industries and municipalities which require large volumes of water to meet their needs. The values derived from these tests are dependent on the well construction, the analytical method used and the hydraulic properties of the unit being tested. Similar values can be anticipated for like units, if the well construction and analytical methods are the same.

Estimation of Transmissivity from Specific-Capacity Values

A rough estimate of the transmissivity can be obtained from specific-capacity data calculated from short-term pumping tests. The MOE requires that a short-term pumping test (one hour) be conducted on each water well constructed in Ontario, and that the information be included on the water-well record, a copy of which goes on file with the MOE. The specific capacity of a well is the rate at which the well is pumped (gpm) divided by the drawdown (feet). In this report, the specific-capacity values are adjusted to a common well radius of 6" and a pumping interval of one hour.

Transmissivities are estimated by the relationship between the transmissivity and the specific capacity of a well as presented in Theis et al (1963) and illustrated in Figure 5 for a storage coefficient of 0.1 and 2×10^{-5}, respectively. The storage coefficient of 2×10^{-5} was used in this study for the bedrock transmissivities. A high specific-capacity value is an indication of a high transmissivity.

The transmissivity data for 177 bedrock wells in the basin are presented on the transmissivity-probability plot in Figure 6. The data indicate that wells finished in the Amabel Formation (median value 380 Igpd/ft.) are more productive than those finished in the Queenston Formation (median value of 38 Igpd/ft).

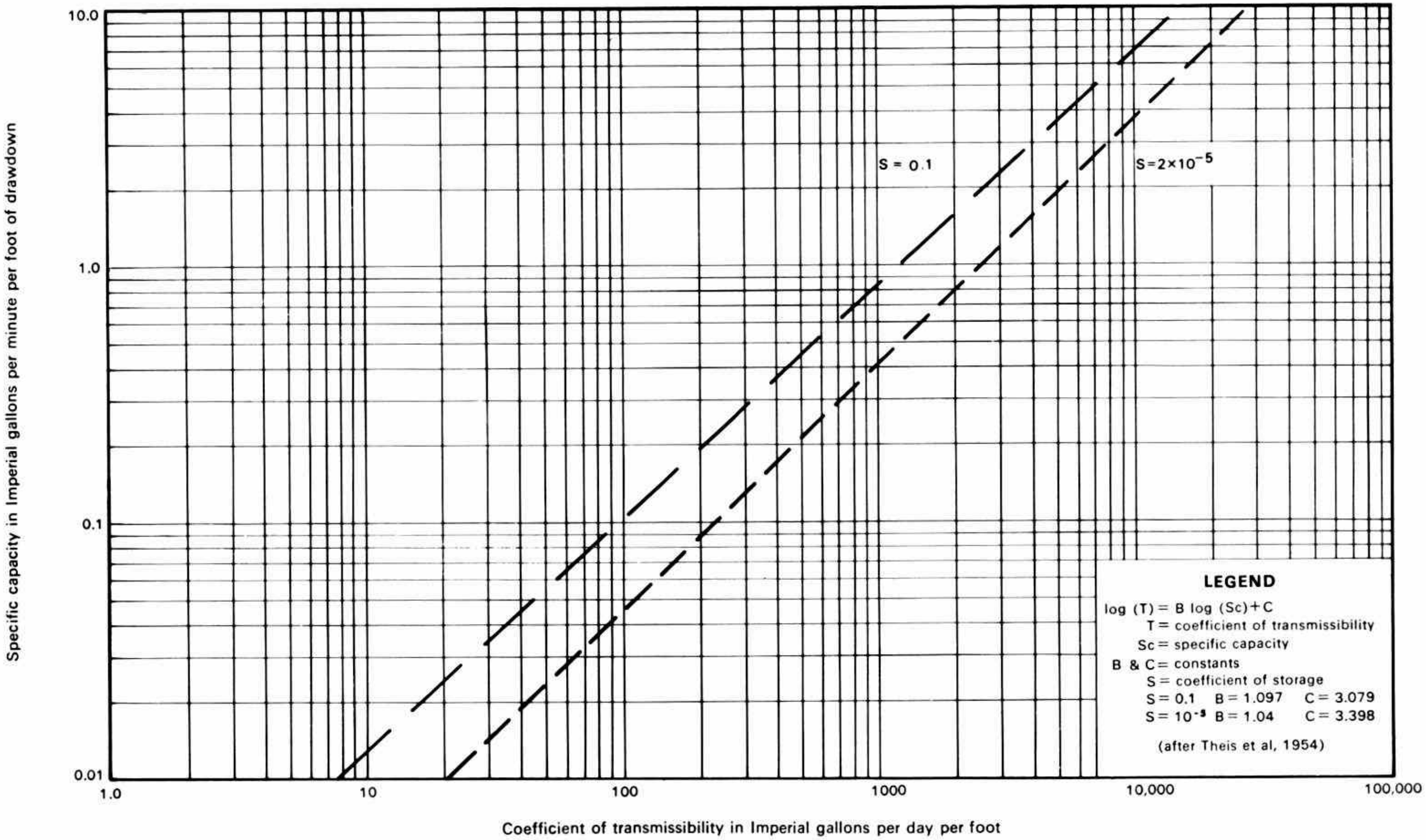


Figure 5. Relationship between specific capacity and the coefficient of transmissibility(transmissivity).

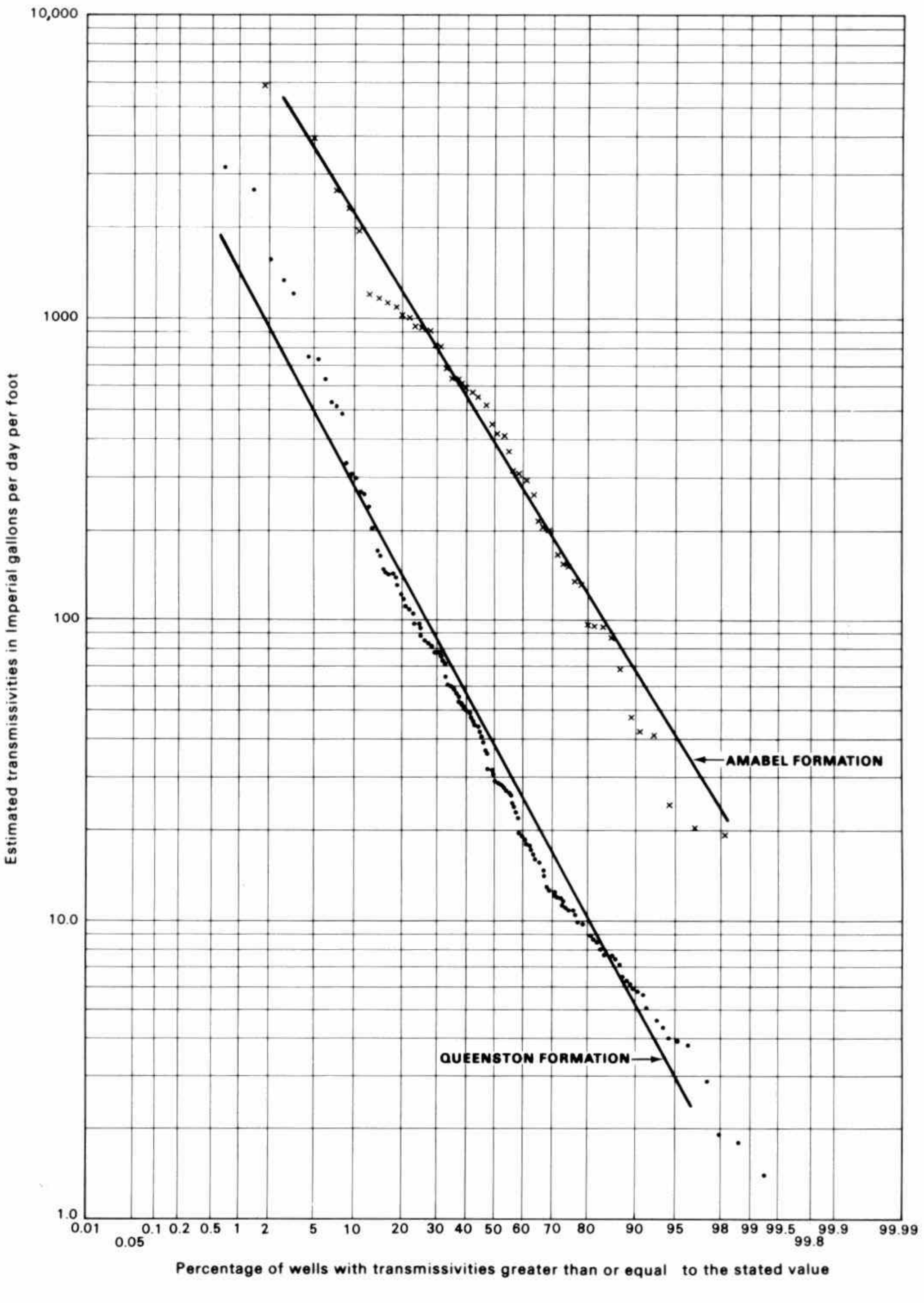


Figure 6. Transmissivity - probability graph for bedrock wells completed in the drainage basin.

Empirical Relationship Between Grain-Size Distribution and Permeability

Estimates of the permeabilities of the coarse-grained deposits were obtained using Hazen's empirical relationship between grain-size distribution and permeability (Hough, 1957). The results are listed below.

Sample No.	Effective Grain Size d_{10} in mm	Coefficient of Permeability Igpd/ft^2	Coefficient of Permeability cm/s
Outwash Deposit			
13	8×10^{-2}	95	5.4×10^{-3}
0-4a 10' SS	3.6	9000	5.1×10^{-1}
31' SS	6.2×10^{-2}	60	3.4×10^{-3}
48' SS	6×10^{-2}	55	3.1×10^{-3}
range		(55-9000)	$(3.1\text{-}510) \times 10^{-3}$
Lake Peel Deposit			
4	6.8×10^{-2}	65	3.7×10^{-3}
7	3.6×10^{-2}	9.2	5.2×15^{-4}

Comparison of the Hydraulic Properties

The hydraulic properties, namely the coefficients of transmissibility, permeability and storage for the two principal aquifers (Outwash Sand and Gravel, Amabel Formation), are compared in Table 8.

TABLE 8. HYDRAULIC PROPERTIES OF THE OUTWASH SAND AND GRAVEL AND AMABEL FORMATION AQUIFERS AS DETERMINED BY DIFFERENT METHODS

Aquifer - Method	Coefficient of Transmissibility Range (Igpd/ft)	Coefficient of Permeability Range (Igpd/ft^2)	Coefficient of Storage Range
OUTWASH SAND AND GRAVEL			
- pumping tests	$(0.3 \text{ to } 5) \times 10^5$	$(0.5 \text{ to } 5.8) \times 10^3$	10^{-1} to 10^{-6}
- grain-size distribution		$(0.6 \text{ to } 90) \times 10^2$	
AMABEL FORMATION			
- pumping tests	$(0.1 \text{ to } 10) \times 10^4$		10^{-2} to 10^{-5}
- specific-capacity values	3.8×10^2 (median value)		
- specific capacity values (Coward and Barouch, 1978)	3.2×10^3 (median value)		
- pumping tests (Coward and Barouch, 1978)	3.1×10^3 (median value)		

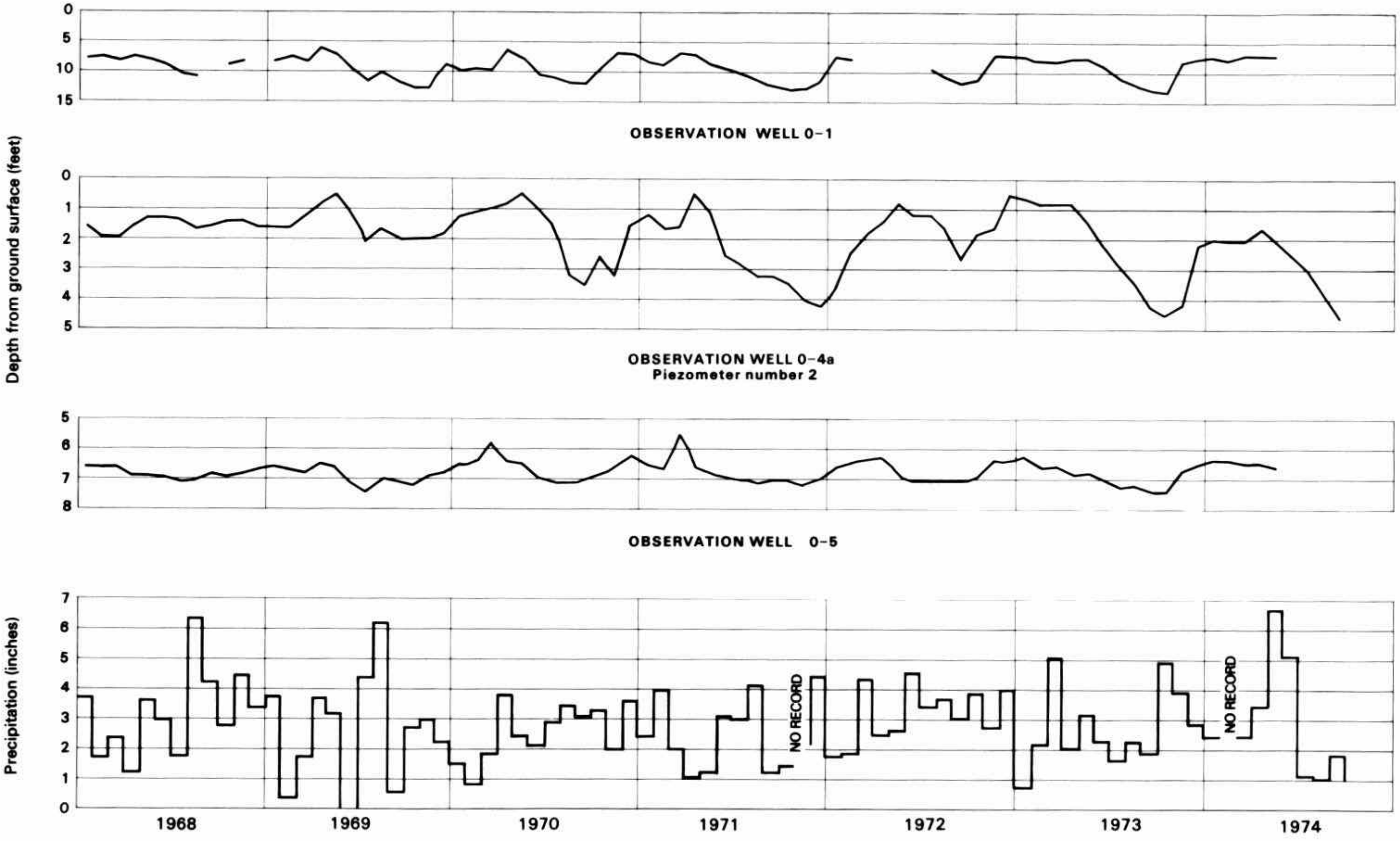


Figure 7. Monthly precipitation, and water-level hydrographs for three observation wells.

The transmissivity values for the Amabel Formation as calculated by Coward and Barouch (1978) for the Blue Springs drainage basin (located to the northwest) are in reasonable agreement with the pumping-test data included in this study. The transmissivities, as established from specific-capacity values in this study, are lower by an order of magnitude. This is attributed to the proximity of the domestic wells used in the analysis to the Escarpment. The Escarpment, as discussed previously, acts as a ground-water sink, lowering the water table along its rim.

GROUND WATER MOVEMENT

Ground water is in a continuous state of flux. The rate of movement (velocity) and the direction of movement are governed by the complex interaction between the distribution of hydraulic conductivity in the geologic materials and the hydraulic gradients. The interpretation of the pattern of ground-water movement within the basin is accomplished by the systematic measurement of water levels in wells in the basin. From water level measurements taken following well construction, it was possible to construct water-level contour maps for the overburden (Map 6) and the bedrock (Map 7). The water-level contours represent lines of equal hydraulic potential, ground-water movement is perpendicular to these contours from areas of high potential to areas of lower potential. The water-level contour map is commonly a subdued replica of the topographic surface map, with lateral ground-water movement occurring in a downslope direction.

This is the case in the drainage basin, with ground water moving down the regional slope from the area west of the Escarpment eastward towards Lake Ontario. Locally, the direction of movement is governed by the distribution of topographic highs and lows with flow from the basin boundaries towards the creeks.

Water-Level Fluctuations

Water-level fluctuations over the long-term, are a reflection of changes in the volume of ground water in storage due to such factors as seasonal variations in infiltration, ground-water withdrawals and changes in land use (i.e. urban development, where surface runoff is diverted to sewers).

In order to monitor changes in water levels in the drainage basin, a network of observation wells (well logs in Appendix I) was established. This network consisted of 8 wells (Map 5), 2 of which had automatic recorders and 6 others were measured weekly by tape. Figure 7 presents hydrographs for observation wells 0-1 (Amabel Dolostone), 0-4a, piezometer #2 (overburden) and 0-5 (Queenston Shale). The water levels generally show a similar pattern of fluctuations, although the magnitude of fluctuation varies, this being related to the storage capacity of the geologic material in which the wells are finished. A well-developed seasonal trend is evident, with a rise in water levels in late winter and early spring and a decline during the summer and fall.

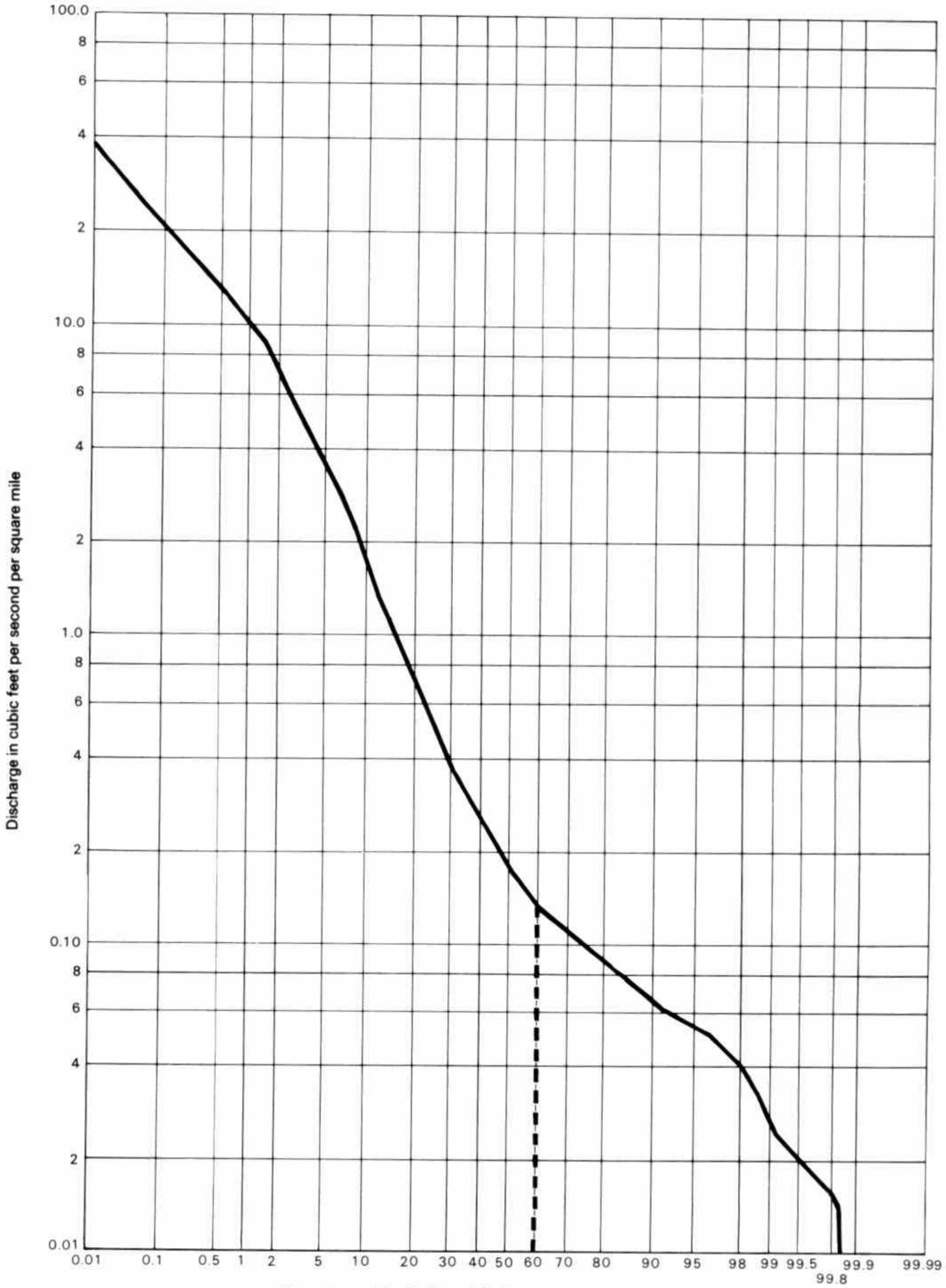


Figure 8. Flow - duration curve for the interval from October 1968 to September 1974 for gauging station 02HB004.

TABLE 9. ESTIMATED ANNUAL HYDROLOGIC BUDGET FOR THE SUB-BASIN ABOVE STREAMFLOW GAUGING STATION 0-1 (02HB201) FOR THE PERIOD OCTOBER 1968 TO SEPTEMBER 1974

Water Year	Precipitation(1) P (inches)	Total Runoff R (inches)	Baseflow B (inches)	Baseflow as a Percentage of		Potential Evapotranspiration E.T. (inches)		Change in Storage ΔS
				Runoff	Precipitation	Munson Index(1)	Indirect	
1968-69	30.28	14.88	4.94	33.2	16.3	21.77	15.40	6.37
1969-70	36.00	8.03	3.53	44.0	9.8	21.91	27.97	-6.06
1970-71*	33.82	11.39	4.53	39.8	13.4	21.66	22.43	-0.77
1971-72	39.14	10.26	3.68	35.9	9.4	21.29	28.88	-7.59
1972-73	35.16	16.50	6.90	41.8	19.6	22.67	18.66	4.01
1973-74	43.87	17.50	6.02	34.4	13.7	22.29	26.37	-4.08
Average	36.38	13.09	4.93	38.2	13.7	21.93	23.28	-8.12 accumulated

TABLE 10. ESTIMATED ANNUAL HYDROLOGIC BUDGET FOR THE TOTAL DRAINAGE BASIN ABOVE STREAMFLOW GAUGING STATION 0-5 (02HB004) FOR THE PERIOD OCTOBER 1968 TO SEPTEMBER 1974

Water Year	Precipitation(2) P (inches)	Total Runoff R (inches)	Baseflow B (inches)	Baseflow as a Percentage of		Potential Evapotranspiration E.T. (inches)		Change in Storage ΔS
				Runoff	Precipitation	Munson Index(2)	Indirect	
1968-69	35.24	14.06	1.18	8.4	3.3	22.58	21.18	1.40
1969-70	30.65	7.04	1.80	25.6	5.9	23.03	23.61	-0.58
1970-71*	31.49	9.05	2.475	27.3	7.9	22.54	22.44	0.10
1971-72	35.68	9.26	1.35	14.6	3.8	22.70	26.42	-3.72
1972-73	32.42	13.76	2.54	18.4	7.8	23.88	18.66	5.22
1973-74	38.00	13.27	2.00	15.1	5.3	23.11	24.73	-1.62
Average	33.91	11.07	1.89	18.2	5.7	22.97	22.84	0.8 accumulated

* Scotch Block Reservoir filled (1) Speyside IHD Met. Station (2) Hornby IHD Met. Station.

TABLE 11. ESTIMATED ANNUAL HYDROLOGIC BUDGET FOR THE SUB-BASIN ABOVE STREAMFLOW GAUGING STATION 0-4 (02HB204) FOR THE PERIOD OCTOBER 1968 TO SEPTEMBER 1974

Water Year	Precipitation(1) P (inches)	Total Runoff R (inches)	Baseflow B (inches)	Baseflow as a Percentage of		Potential Evapotranspiration E.T. (inches)		Change in Storage S
				Runoff	Precipitation	Munson Index(1)	Indirect	
1968-69	35.24	11.09	0.28	2.5	0.8	22.58	24.15	-1.57
1969-70	30.65	5.01	0.56	11.2	1.8	23.03	25.64	-2.61
1970-71	31.49	7.97	0.83	10.4	2.6	22.54	23.52	-0.98
1971-72	35.68	incomplete	record	-	-	22.70	-	-
1972-73	32.42	10.67	0.84	7.9	2.6	23.88	21.75	2.13
1973-74	38.00	19.36	0.73	3.8	1.9	23.11	18.64	4.47
Average(3)	33.56	10.82	0.65	7.2	1.9	23.03	22.74	1.44 accumulated

(1) Speyside IHD met. station

(3) averages do not include data from 1971-72

HYDROLOGIC BUDGET

The hydrologic budget, a quantitative statement of basin recharge and discharge over a set interval of time, can be expressed by the following simplified water-balance equation (Equation 1):

$$P = R + ET \pm \Delta S \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where:

P = total precipitation
R = streamflow = baseflow (B) + surface runoff (R_s)
ET = evapotranspiration
ΔS = change in storage of ground water, surface water and soil moisture

Annual budgets (interval 1968 - 1974) for two sub-basins, namely the area above streamflow gauging station 0-1 and that above streamflow gauging station 0-4 and for the basin as a whole, above streamflow gauging station 0-5 are presented in tables 9, 10 and 11.

Precipitation data were collected from the Hornby and Speyside IHD meteorological stations. The ground-water contribution to streamflow, also known as baseflow (B), was estimated from hydrometric records by the method attributed to Wundt by Meyboom (1967). This method assumes that the monthly minimum streamflow is taken as a measure of baseflow and that the annual baseflow component is therefore the total mean monthly minimum flows. Evapotranspiration was estimated by the Munson-Index Method (ASCE, 1966) and compared against the Indirect Method (solving for E.T. in the simplified balance equation). The change in storage component (ΔS) was not measured directly and has been included only to balance the equation. All values are expressed in inches of precipitation per unit area per year.

A flow-duration curve (Figure 8) was prepared for gauging station 02HB004 for the purpose of comparing the baseflow contribution estimated in Table 10 with that estimated from the flow-duration curve. According to Wyrick and Lloyd (1968), baseflow may be estimated from stream discharge, as that portion of the daily discharge which was exceeded 60% and 90% of the time. A value of 60% was used in this study based on this Ministry's experience in southern Ontario. This equates to a mean annual baseflow of 0.135 cfs/mi^2 or 1.83 inches precipitation/year. This value compares well with the baseflow value of 1.89 inches from Table 10.

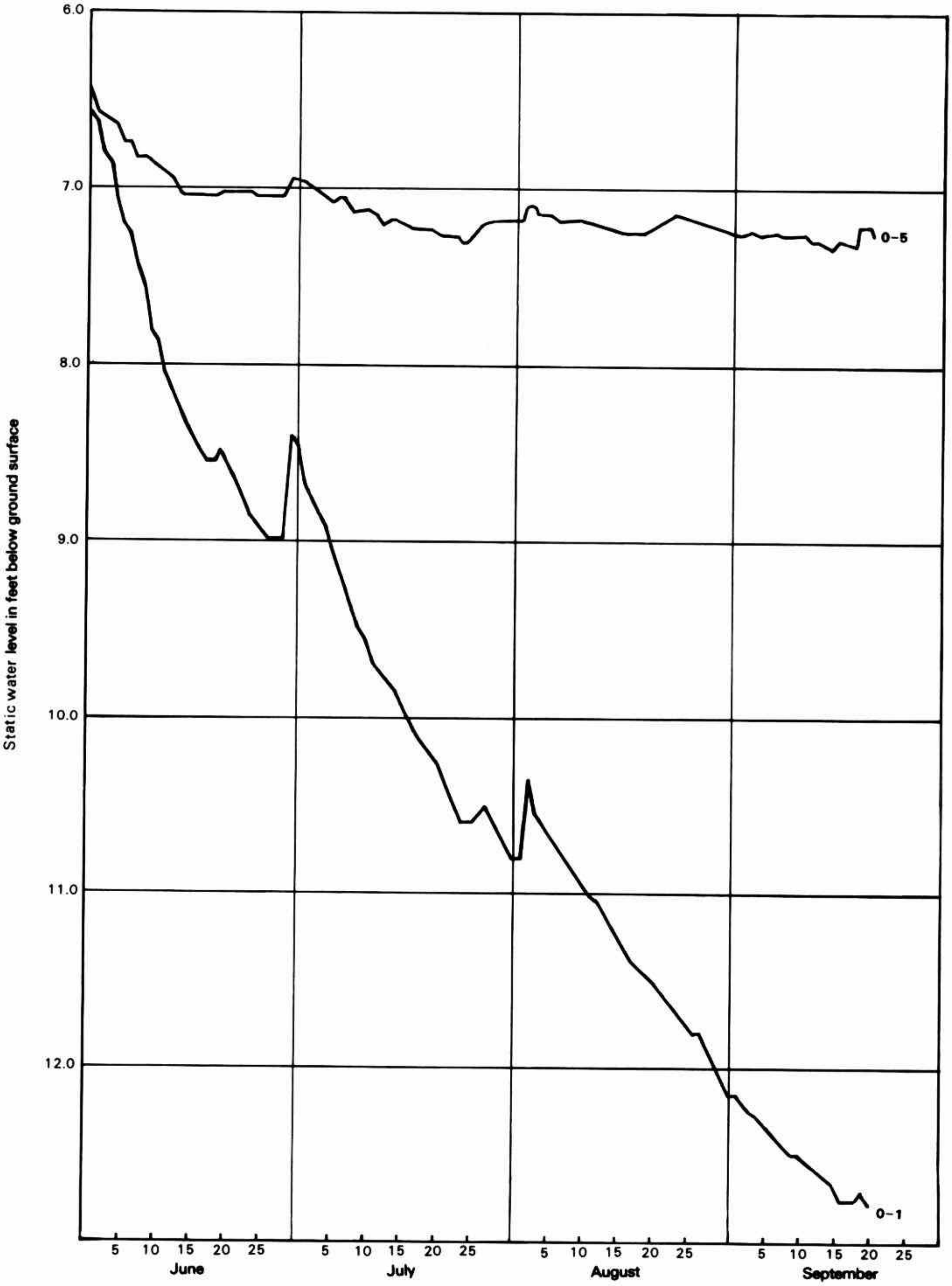


Figure 9. Static water levels in observation wells O - 1 and 0 - 5 during the summer months of 1973.

GROUND WATER RECHARGE

Ground-water recharge in the basin can be estimated by solving Equation 2 (Coward and Barouch, 1978). Recharge is expressed as:

$$R = B + \Delta GWS \quad \ldots\ldots\ldots\ldots\ldots (2)$$

where:

R = ground-water recharge,
B = baseflow,
and Δ GWS = change in ground-water storage.

The change in ground-water storage was approximated by:

$$\Delta GWS = \Delta(\overline{WL}) \cdot Sc \cdot A \quad \ldots\ldots\ldots\ldots\ldots (3)$$

where:

$\Delta \overline{WL}$ = change in mean water level in basin
Sc = mean coefficient of storage
and A = drainage basin area

Combining equations 2 and 3:

$$R = B + \Delta(\overline{WL}) \cdot Sc \cdot A \quad \ldots\ldots\ldots\ldots\ldots (4)$$

The change in mean water level (Table 12) was estimated by obtaining the mean water level for seven observation wells (Map 5) in different parts of the basin for October 1st of each year of record and calculating the change in level from year to year.

Ground-water recharge during certain periods of the year, especially in the summer, approaches zero. This is reflected in the hydrographs of observation wells (Figure 9), where a decline in the water level is shown. An examination of the well records identified six periods of a month in duration, during which recharge appeared to be zero. Where recharge is zero, Equation 4 can be restated for the purpose of estimating the mean coefficient of storage for the basin, as:

$$Sc = \frac{-B}{\Delta\overline{WL}.A} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

By substituting in the mean change in water level and the estimated baseflow (Table 10), the coefficient of storage (Table 13) was found to range from 0.002 to 0.01, with a mean of 0.008. This mean value was then used in Equation 4 to calculate yearly recharge values for the total period of record. These values are listed in Table 14. The mean annual recharge for the basin was calculated to be 1.87 inches precipitation/year.

TABLE 12. STATIC WATER LEVELS FOR VARIOUS OBSERVATION WELLS IN BASIN

Observation Well	Depth in feet from Surface Measured on October 1 of each Year 1968	1969	1970	1971	1972	1973	1974	Change in Level Over Period of Record
0-1	8.35	12.0E	9.0E	12.1	11.1	12.7	9.5	-1.15
0-2a	6.1	8.4	9.1	10.1	7.5	10.4	10.2	-4.1
0-2b piez.#2	11.7	12.6	12.4	12.5	12.0	12.8	12.5	-0.8
0-3 piez.#1	13.75	13.6	13.5	13.5	13.5	13.2	12.7	1.05
0-4a piez.#1	0.6	2.1	2.3	3.6	1.8	4.3	4.5	-3.9
0-4b piez. #1	11.95	12.0	11.85	12.1	11.8	12.0	11.85	0.1
0.5	6.75	7.0	6.75	7.0	6.8	7.15	5.0	1.75
Mean Ground-Water Level	8.46	9.67	9.27	10.13	9.21	10.36	9.46	-1.0
Annual Change in mean Ground-Water Level.	-1.21	+0.4	-0.86	+0.91	-1.15	+0.9		

TABLE 13. COEFFICIENT OF STORAGE CALCULATED FROM MEAN WATER LEVEL DECLINE IN BASIN DURING PERIODS OF LITTLE OR NO GROUND-WATER RECHARGE.

Period	ΔWL (ft)	Baseflow (B) cfs	acre ft. / month	Coefficient of Storage (Sc)
July 5 to Aug. 5/68	-0.90	7.4	455.0	0.0103
Aug./70	-0.58	1.0	61.5	0.0021
July 10 to Aug.10/71	-0.74	6.2	381.2	0.0105
Sept./71	-0.54	4.4	261.8	0.0098
July/73	-0.87	5.4	332.0	0.0077
Aug./73	-0.65	4.6	282.8	0.0088
	Mean coefficient of storage			0.0082

$$Sc = \frac{-B}{\Delta \overline{WL} \cdot A}$$

where

Sc = coefficient of storage
Δ WL = change in mean water level in basin
B = baseflow for period
A = basin area (77 mi^2

TABLE 14. GROUND-WATER RECHARGE FOR THE INTERVAL FROM OCTOBER 1968 TO SEPTEMBER 1974 FOR THE DRAINAGE BASIN

Water Year	ΔWL Change in Water Level (inches)	Sc Mean Coefficient of Storage	= ΔGWS Change in Ground-Water Storage (inches)	+ B Baseflow (inches)	= R Recharge (inches)
1968-69	-14.57	0.008	-0.120	1.18	1.06
69-70	0.48	0.008	0.003	1.80	1.80
70-71	-10.28	"	-0.085	2.475	2.39
71-72	10.97	"	0.090	1.35	1.44
72-73	-13.80	"	-0.113	2.54	2.43
73-74	10.80	"	0.089	2.00	2.09
			mean ground-water recharge		1.87

WATER USE IN THE BASIN

Water use in and adjacent to the basin is discussed by the principal use to which it is put, namely:

1. irrigation,
2. municipal water supply,
3. rural domestic water supply.

The type of supply, surface or ground water, is dependent on the quantity and quality of the water available and the economic considerations inherent in extracting the supply and transporting it to where it will be used.

The existing water resources, as were noted earlier, consist of those waters which can be pumped from ponds and streams or from the subsurface. The availability of surface waters is governed chiefly by quantity, this being especially critical during "dry" periods. It is important that streamflow is maintained at a level where downstream uses are not detrimentally affected. This consideration is also of concern with ground-water supplies. Excessive use can "mine" available supplies, to a point where individual water takings have led to interference complaints.

In order to ensure the equitable use of supplies, particularly during drought, a water-taking permit program was established by the former Ontario Water Resources Commission for the Province in 1961. The Permit to Take Water Program is now administered by the Ministry of the Environment, the legislation being defined in the Ontario Water Resources Act, Section 37. The program covers those takings of more than 10,000 gallons of water per day from new wells, streams, inlets, diversions or storage works for purposes other than domestic, stock watering or firefighting.

A total of 40 permits have been issued in and adjacent to the basin. Data on these permits are included in the table on Map 8.

Irrigation

Irrigation is practiced during the summer months when it is essential to maintain soil moisture levels for the growth of crops and the aesthetic maintenance of lawns (e.g. golf courses). As based on the water-taking permits, the water takings for this purpose amount to 3.25 million gallons per day during the summer months. A large portion of the irrigation water is lost from the basin water supply through evapotranspiration.

Municipal Water Supplies

There are no municipal water takings in the basin. The communities of Georgetown and Milton, just outside the basin, however, utilize ground-water supplies obtained from aquifers which are the same as those in the basin. Data from the Milton system are included for comparison, on the table on Map 8.

Rural Domestic Water Supplies

Rural water needs are met by ground water pumped from domestic water wells. Based on the water-well records and interviews with local residents, the majority of the basin is underlain by favourable hydrogeologic conditions resulting in a high rate of success in the drilling of wells with satisfactory water supplies. Insufficient water supplies are a problem in those areas south of Hwy. 401 with thin overburden cover. Water in these areas is obtained from large diameter wells which encounter the thin sand and silt stringers in the overburden and from wells finished in the upper, fractured portion of the Queenston Formation. Many of the shallow wells in this area go dry during the summer. The rural water demand in the basin is estimated to be approximately 3000 Igpd/mi^2 (based on a total of 578 wells at a rate of 400 Igpd each).

HYDROCHEMISTRY

General

A total of 46 stream and well samples were collected from within the basin in September 1974. These samples were collected along five traverses (perpendicular to the elongated direction of the basin), to determine the natural water quality for the principal hydrogeologic units in the basin.

The samples collected in September 1974 were analysed for bicarbonate alkalinity, pH, and temperature at the time of sampling. The results of the field tests and those of the laboratory analyses are presented in Table 16 and diagramatically in the Piper Trilinear plots, figures 11 and 12. The locations of the samples are shown in Figure 10.

The ion balances, equivalents per million (milliequivalents per litre) and various ratios between different ions were calculated for each sample, in addition to means for groups of samples, by a computer program written by J. Coward (personal communications). The accuracy and completeness of the chemical analyses of the water samples were checked by the cation-anion balance for each sample. An arbitrary limit of 7.5% error was set in order to compensate for the inherent inaccuracy in the reproducibility of the analytical results and for incomplete analyses, as only the major ions were analysed. All samples which had ion imbalances in excess of 7.5% error were not included in the statistical analyses.

Bedrock Water Quality

A total of seven samples were collected from wells finished in the Amabel (dolostone) Formation and 14 samples from the Queenston (shale) Formation. The maximum, minimum and mean values of various inorganic chemical constituents for each unit are presented in Table 15 and illustrated graphically in Figure 11.

The analyses, for the most part, reflect certain chemical characteristics which are often found in ground waters associated with carbonate and shale terrains. Samples collected from wells finished in the Amabel Formation are calcium-magnesium-bicarbonate waters based on the predominant cations-anions present (Figure 11), these ions resulting from the solution of calcite and dolomite minerals in the bedrock. The water samples are typically hard (mean 312.5 mg/L) and are relatively lower in total dissolved solids, sodium, chloride and sulphate content than samples collected from either the overburden or the Queenston Formation.

The results of analyses of samples collected from wells finished in the Queenston shale reflect the greater variety of chemical components in this shale when compared with the Amabel dolomite. These samples are considerably higher in total dissolved solids, sulphate, chloride and sodium content than samples collected from the other hydrogeologic units (Table 15). Because of the generally poorer water quality in the shale, it is recommended that wherever possible a water supply be sought in the overburden. Map 4 can be used as a guide to identify areas in which there is potential for establishing a supply with an overburden well.

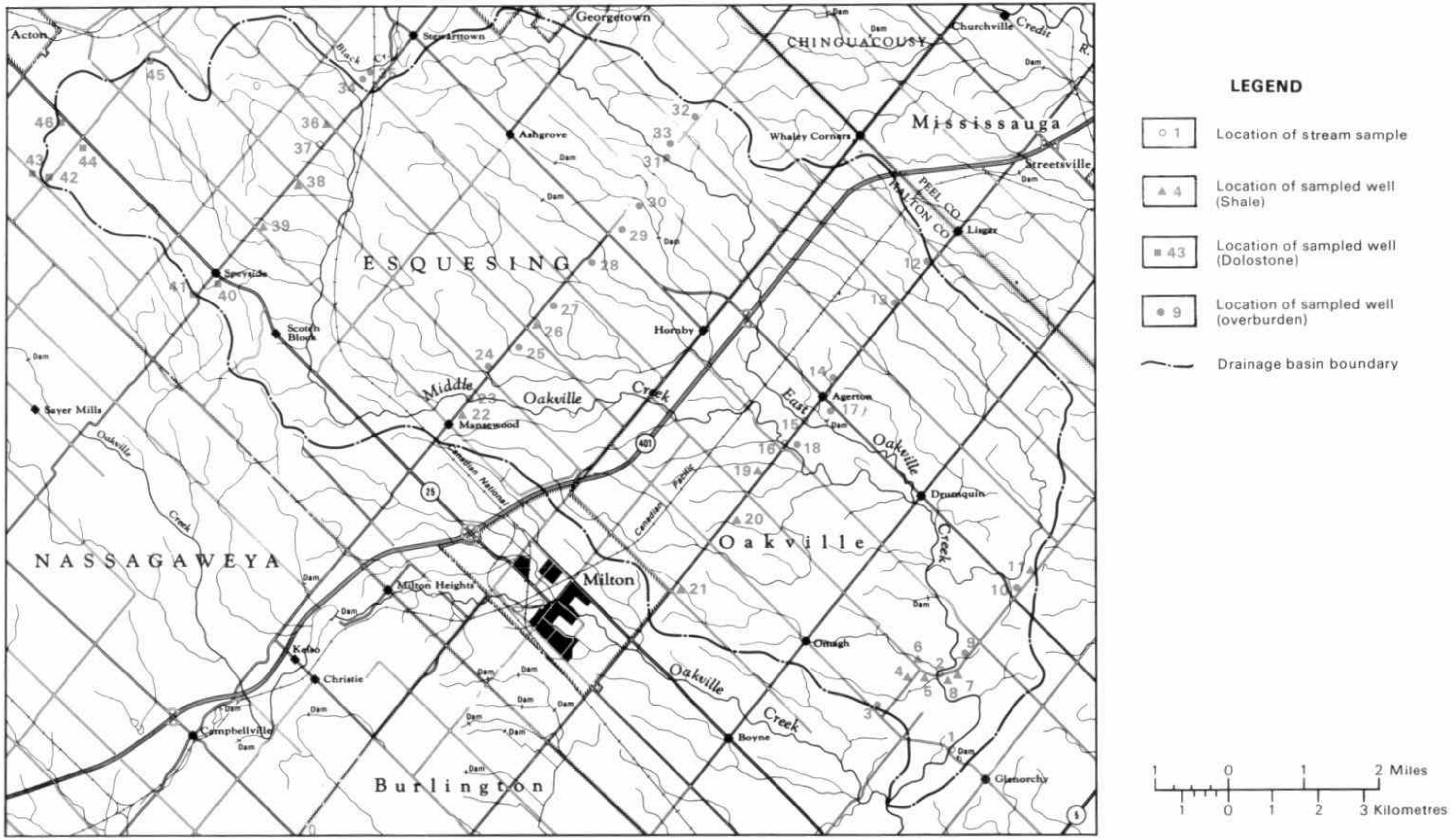


Figure 10. Locations of ground- and surface-water sampling points.

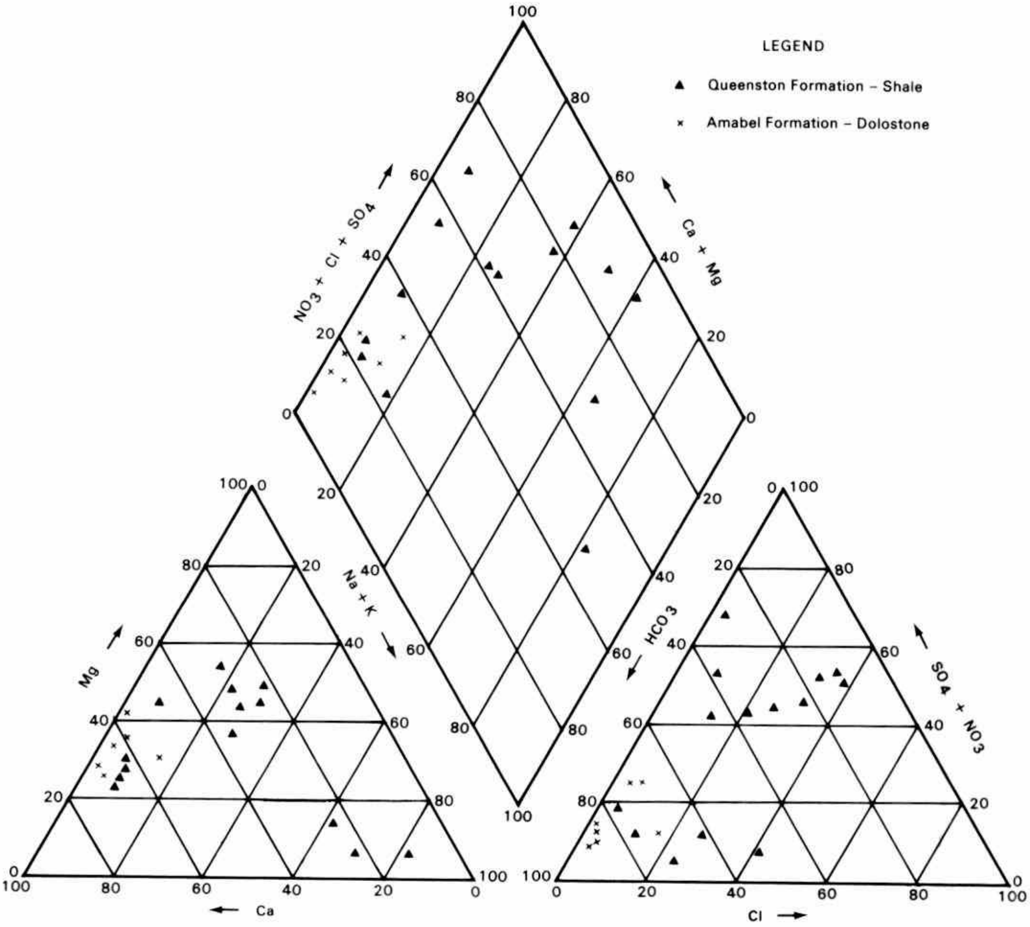


Figure 11. Major-ion hydrochemistry of water in the bedrock.

Overburden Water Quality

A total of 18 water samples were collected from the overburden. The analyses of water samples collected in the overburden display a considerable variability in chemical composition as is evident from Figure 12. This variability is probably related to a variety of factors including the variable mineral composition of the overburden which has been largely derived from the underlying bedrock, the depths at which the samples were collected and the influences of mans' activities (i.e. high chlorides from road deicing).

The samples are for the most part, of poorer quality than those of the Amabel Formation but of better quality than those collected from the Queenston Formation (Table 15).

Suitability of Water for Domestic Use

The chemical quality of a ground or surface water is an important consideration in judging its suitability for use as a domestic water supply. Ideally, the chemical quality of the raw water supply should be such that it meets certain water quality criteria imposed on it by its intended use, without incurring the added cost of water treatment. In order to assist the public in assessing the suitability of a water supply for drinking purposes the MOE has established a number of quality objectives defined as Drinking Water Quality Criteria. These objectives are presented in the MOE publication "Drinking Water Objectives" (February, 1978). Although the water quality criteria listed in the publication apply specifically to public distribution systems, the recommended limits are a useful guide in judging the acceptability of a supply for private use.

Common chemical parameters of concern in water and their recommended limits are:

chloride	250 mg/l
iron	0.3 mg/l
nitrate as N	10 mg/l
sulphate	250 mg/l
total dissolved solids	500 mg/l

Recommended limits for hardness have not been assigned in that its acceptability in a supply is dependent on individual requirements and preferences. A common classification scheme for hardness (Hem, 1970 after Durfor and Becker, 1964) is as follows:

Hardness Range (mg/l of $CaCO_3$)	Description
0-60	soft
61-120	moderately hard
121-180	hard
more than 180	very hard

The microbiological content of the water supply should be established prior to use by submitting a sample of the water to the local Ministry of Health representative for examination. Nuisance organisms should be absent from water supplies. Where they occur it will be necessary to disinfect the water supply prior to use.

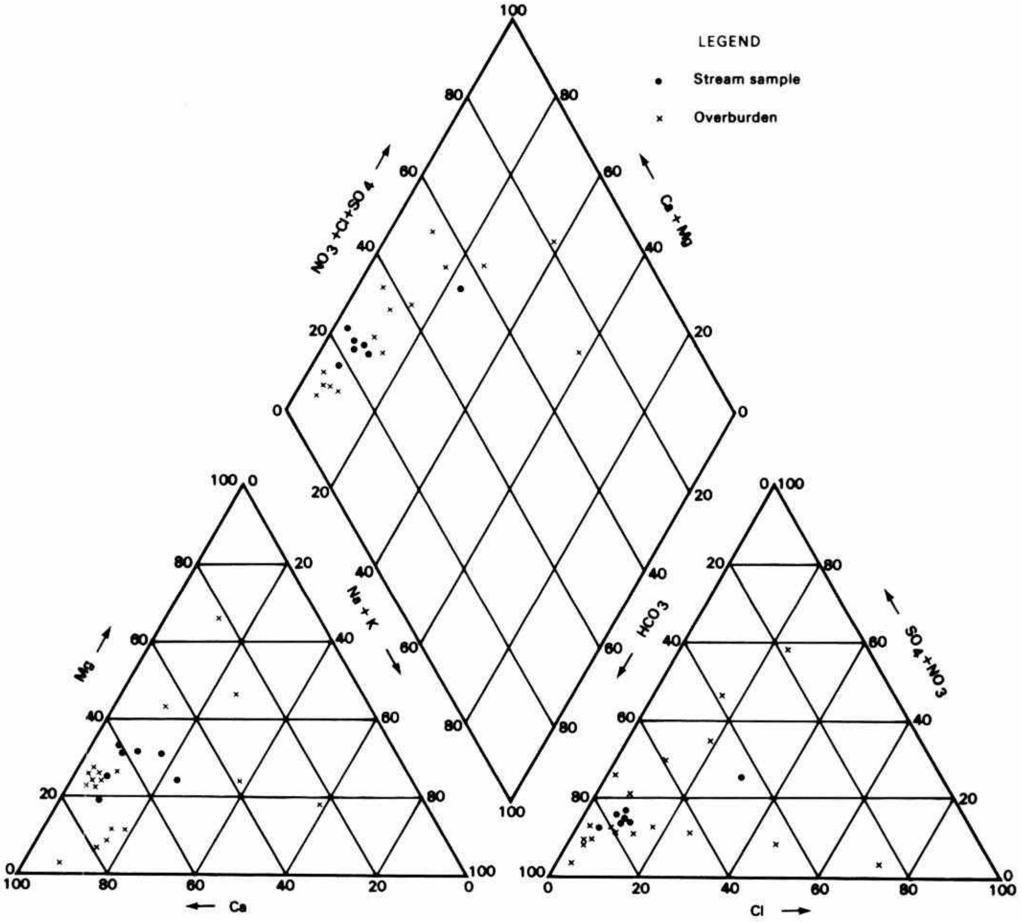


Figure 12. Major-ion hydrochemistry of water in the overburden and in streams.

TABLE 15. WATER QUALITY SUMMARY

				Ionic Concentrations (mg/L)									
		pH (field)	Ca	Mg	Na	K	HCO_3 (field)	SO_4	Cl	NO_3 as N	Total Iron	Total Dissolved Solids mg/L	Total Hardness as $CaCO_3$ mg/L
Overburden Samples (18 samples)	Max	7.50	162.0	144.0	145.0	53.0	468.0	420.0	265.0	32.0	1.50	1184.4	678.9
	Min	6.50	42.0	1.0	2.0	0.7	28.0	9.0	2.0	<.2	<.05	200.1	111.5
	Mean*	6.99	94.7	30.6	26.2	6.6	222.0	70.9	53.8	4.0	0.31	589.2	362.4
Bedrock Samples Amabel Formation (7 samples)	Max	7.35	118.0	35.0	24.0	29.0	288.0	80.0	44.0	14.0	0.9	640.3	438.8
	Min	7.10	72.0	19.0	2.0	0.3	212.0	21.0	4.0	<.2	<.05	430.1	291.0
	Mean*	7.27	81.2	26.7	7.0	0.7	242.7	37.2	12.7	0.9	0.26	465.4	312.5
Queenston Formation (14 samples)	Max	7.60	248.0	194.0	392.0	19.0	460.0	1000.0	495.0	6.9	12.0	2670.6	1418.0
	Min	6.70	24.0	1.0	2.0	1.0	56.0	35.0	6.0	<.2	<.05	445.9	92.9
	Mean*	7.06	113.4	60.3	123.7	10.8	245.0	342.0	149.2	0.9	.75	1119.0	545.8
Stream Samples (7 samples)	Max	7.60	77.0	25.0	38.0	6.2	220.0	59.0	99.0	0.4	1.0	494.2	282.7
	Min	6.85	54.0	12.0	4.0	1.0	160.0	29.0	9.0	<.2	<.05	352.8	213.1
	Mean*	7.41	66.8	19.3	11.7	2.8	186.8	36.6	28.7	0.3	0.56	394.9	246.4

* does not include samples which have ion imbalances greater than 7.5%

The distribution of values for the above chemical parameters are presented in figures 13 to 18. Each parameter is briefly discussed in the following sections.

Chloride - The criterion for chloride of 250 mg/L in water supplies is based on palatability rather than on physiological effects. Whereas chloride concentrations in the same general order of the criterion impart a "salty taste" to water, there are no known health effects associated with high concentrations in drinking water.
The distribution of chloride concentrations in water samples is illustrated in Figure 13 and is summarized on Table 15 by the source of the sample. Three water samples had chloride concentrations in excess of 250 mg/L. These samples were collected in the Agerton area. Wells finished in the Queenston Formation had the highest mean chloride concentration (149.2 mg/L) while those in the Amabel Formation had the lowest (12.7 mg/L).

Iron - Iron is primarily a nuisance when found in water in concentrations of more than a few tenths of a milligram per litre. It can cause the staining of clothes, plumbing and porcelain, clog pipes, filters and tanks and will impart a bitter metallic taste to water. Iron commonly occurs in two forms, a dissolved form, where it is colourless but can be tasted, and an oxidized form where it precipitates out of solution as reddish brown flakes. The criterion of 0.3 mg/L is related to aesthetics rather than to health effects.
A total of 14 ground-water and 5 surface-water samples had iron concentrations greater than 0.3 mg/L (Figure 14). In general, water samples collected from wells finished in the Queenston Formation or from overburden wells in the clay, clay-till plain area, had higher iron concentrations than those wells finished in the Amabel Formation and outwash sand and gravel deposits (Table 15).

Nitrate - Nitrate concentration (as N) in water in excess of 10 mg/L, is generally regarded as being potentially dangerous to infants where the water is used in infant feeding formulas. In that nitrate in water is commonly indicative of contamination by organic wastes from such sources as domestic septic systems, feedlots and barnyards and heavily fertilized fields, its presence in a water supply is suggestive of such contamination and may flag related bacteriological problems. Three ground-water samples had nitrate concentrations in excess of 10 mg/L. All three samples were collected from wells on farms and the high concentrations may be related to farm activities (i.e. barnyard wastes or fertilizers).

Sulphate - Sulphate, in combination with magnesium and calcium can act as a mild laxative for unacclimatized users when present in water in concentrations in the range of a few hundred milligrams per litre. The criterion of 250 mg/L is based on this effect.
Ten wells contained waters with sulphate concentrations in excess of 250 mg/L, eight of which were finished in the Queenston Formation (Figure 16). The mean sulphate concentration (Table 15) for the water samples collected from this Formation is 342.2 mg/L.

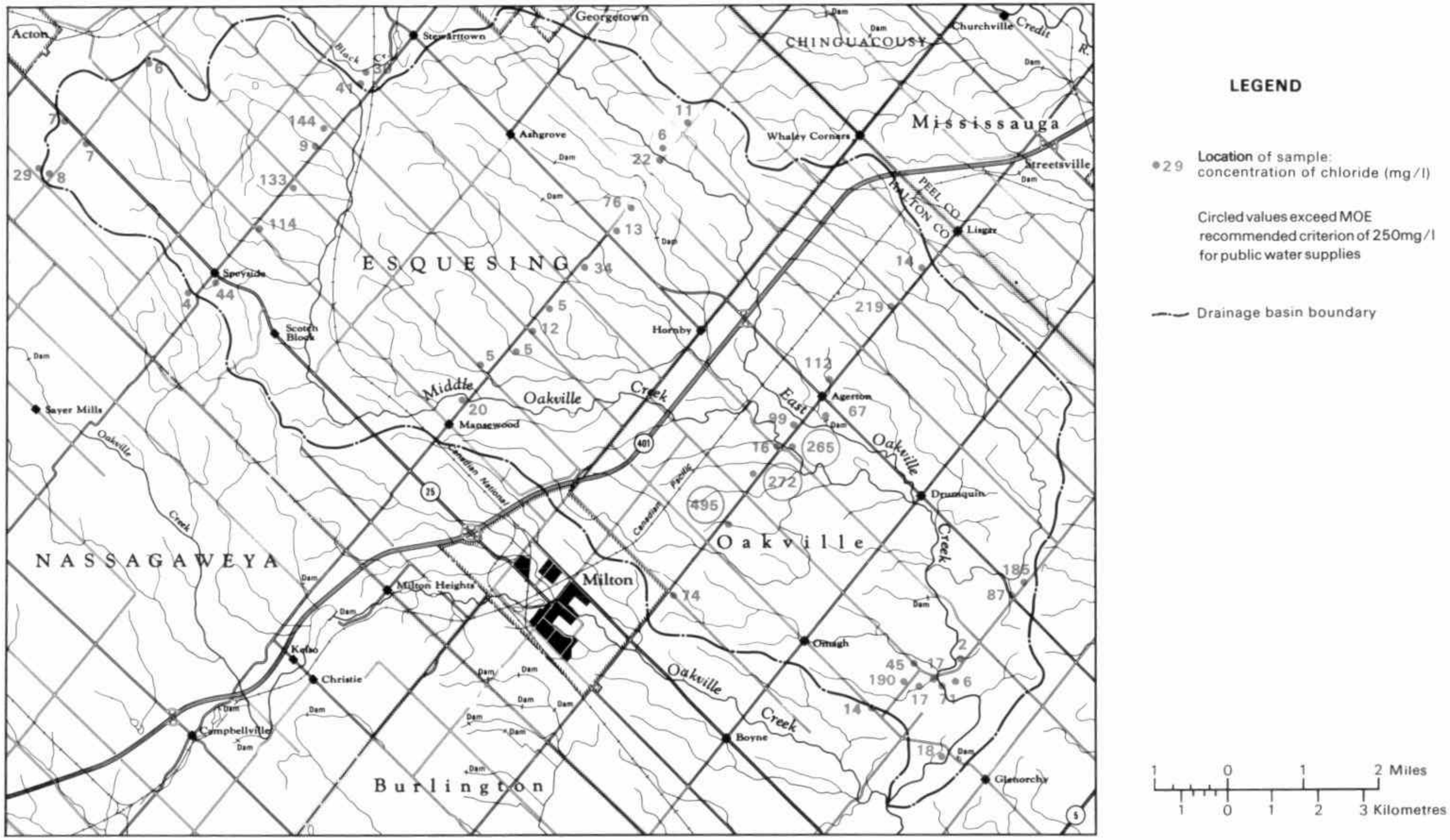


Figure 13. The concentration of chloride in ground water and surface water.

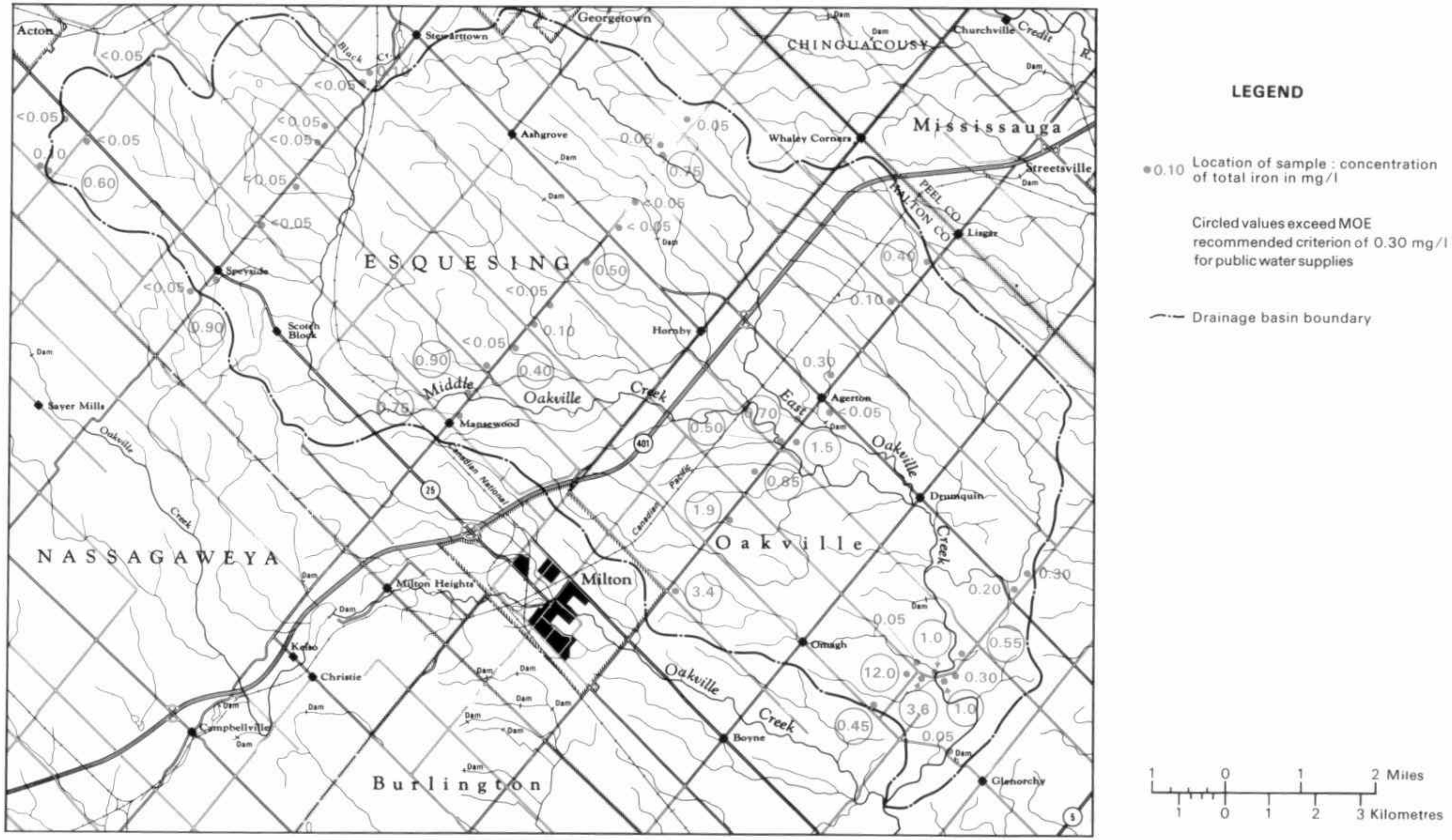


Figure 14. The concentration of total iron in ground water and surface water

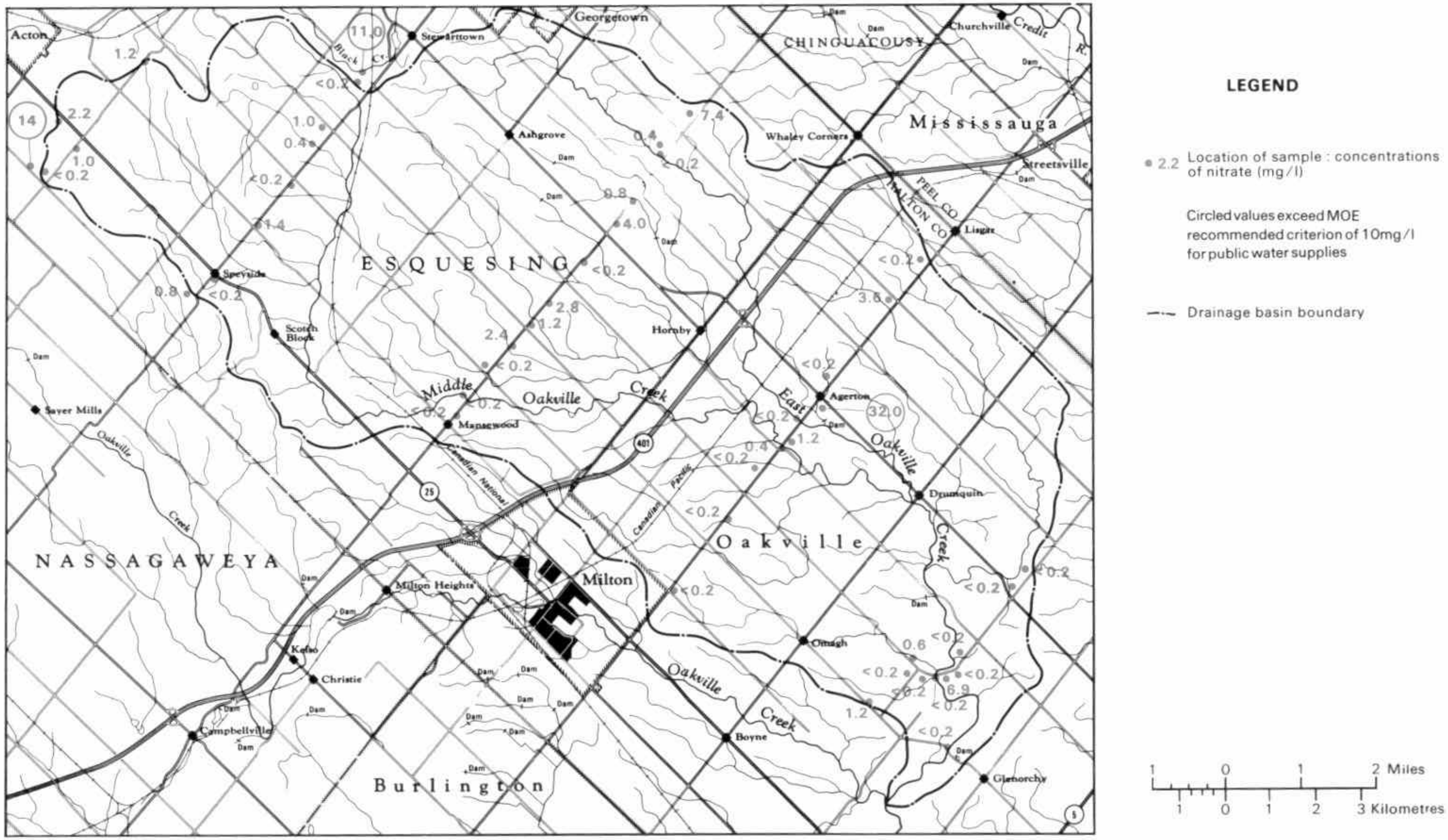


Figure 15. The concentration of nitrate in ground water and surface water.

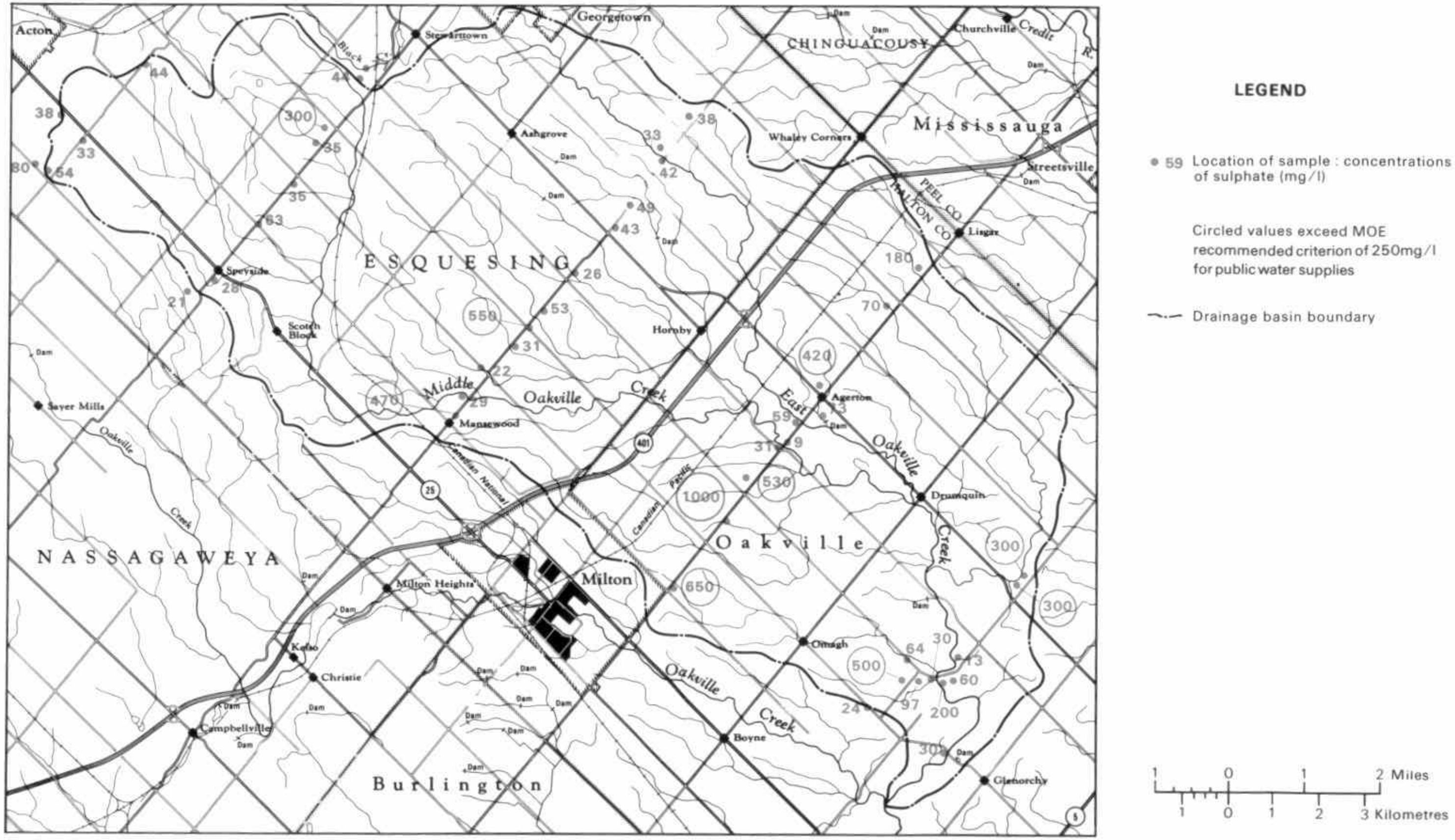


Figure 16. The concentration of sulphate in ground water and surface water.

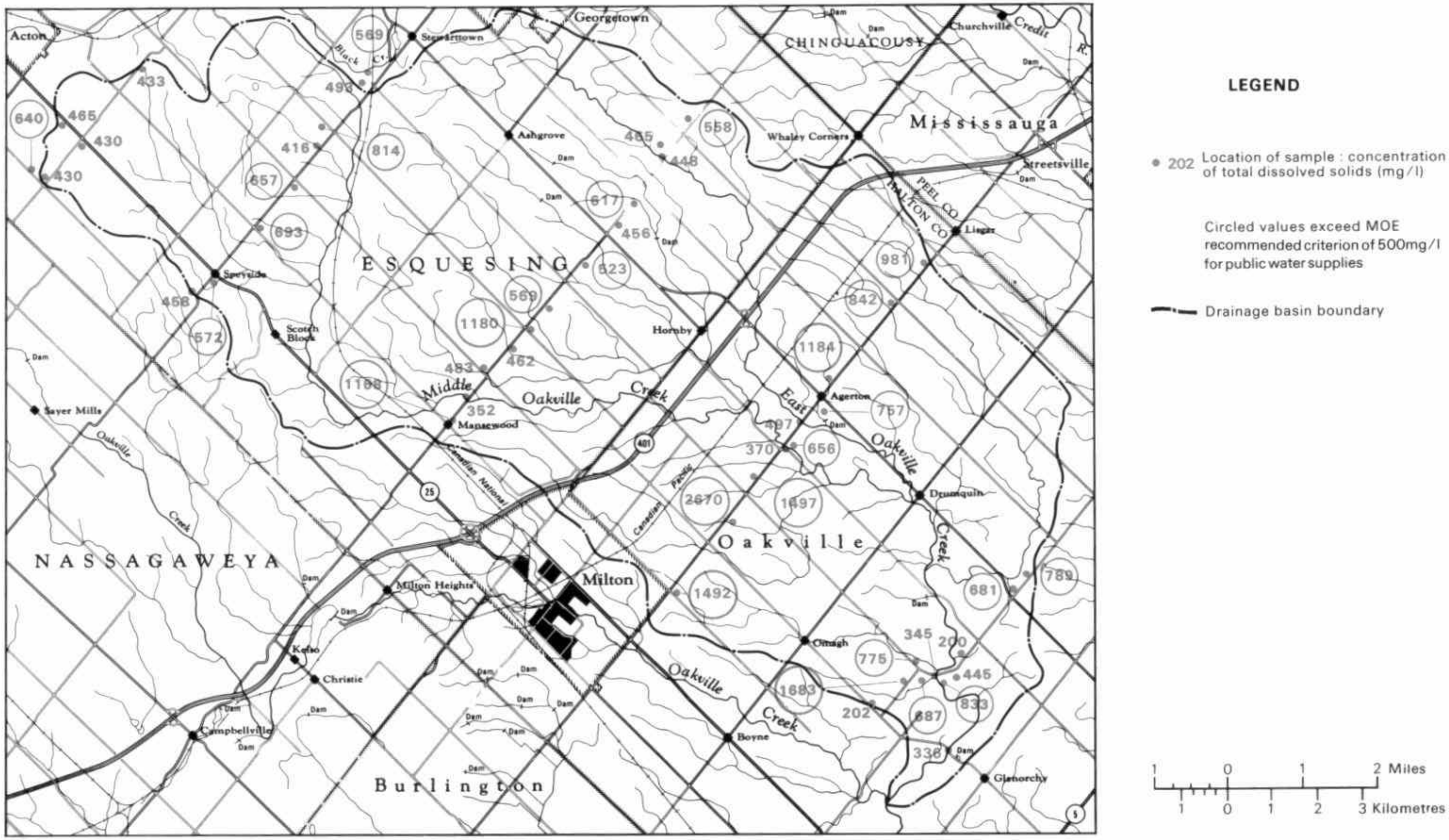


Figure 17. The concentration of total dissolved solids in ground water and surface water.

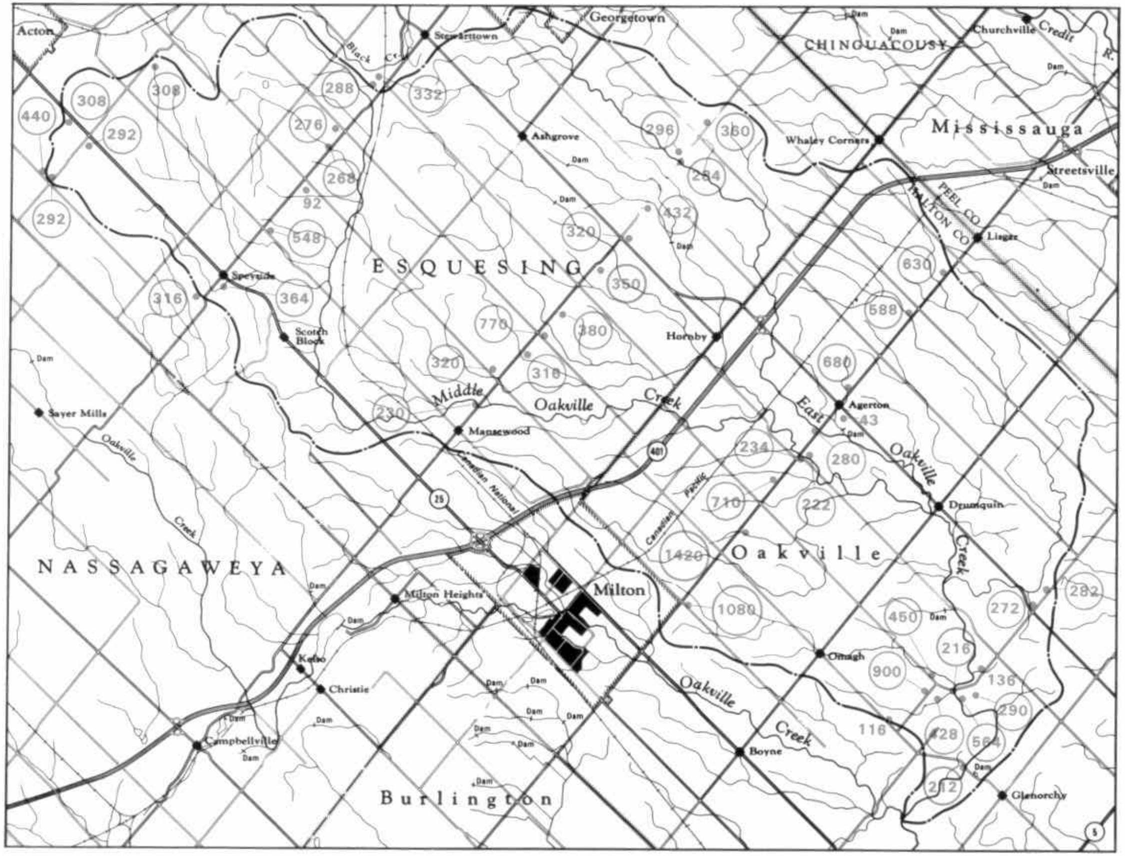


Figure 18. Total hardness of ground water and surface water.

LEGEND

● 92 Location of sample : hardness of water (mg/l)

Circled values indicate "very hard" water according to the following classification (Hem,1970):
Less than 60 – **soft**
60 – 120 – moderately hard
120 – 180 – hard
more than 180 – very hard

—·— Drainage basin boundary

1 0 1 2 Miles
1 0 1 2 3 Kilometres

Total Dissolved Solids - The total dissolved solids (TDS) content of water represents the sum of the dissolved anions and cations. The criterion of 500 mg/L is somewhat arbitrary in that waters of much higher TDS can be consumed without harmful effects. This parameter is useful in judging the general suitability of a water.

Over one-half of the water samples have TDS values in excess of the criterion. These samples are distributed throughout the basin (Figure 17).

Hardness - Hardness in water is characterized by scale in kettles and excessive soap consumption. This property is due primarily to dissolved calcium and magnesium in the water. Areas in which the ground waters are in contact with carbonate minerals commonly have "hard" water. This is the case in the basin, where, with the exception of four samples, all of the samples can be classified as being "very hard" (Figure 18).

Suitability of Water For Irrigation

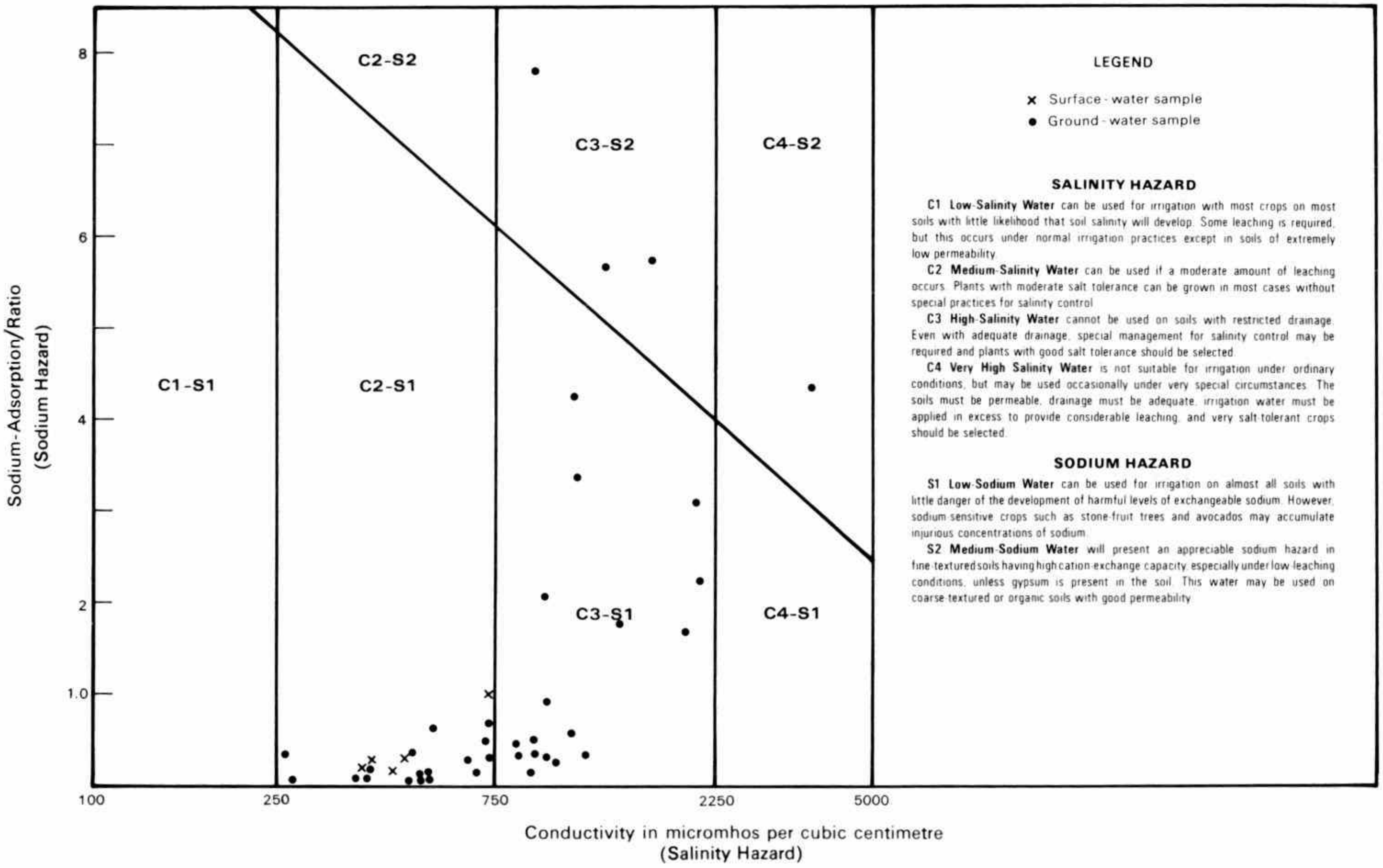
Ground and surface waters are used in the basin for the irrigation of golf courses and certain crops (Map 8). The chemical quality of such waters should be considered in evaluating their suitability for use for irrigation. In general, only a portion of the mineral content in waters is taken up by plants, the bulk of the dissolved minerals are left behind in the soil, normally in solution in residual water. Where the concentrations of these minerals are allowed to rise too high, (i.e. in poorly drained soils) this will interfere with the osmotic process by which plants are able to absorb water, thereby reducing their water uptake. In addition, the continued use of such waters, will through ion-exchange of minerals in the water and soil, reduce the soil permeability and thus effectively reduce the infiltration of irrigation water.

Two common parameters for judging the suitability of waters for irrigation are the sodium-absorption-ratio (SAR) and the electrical conductivity (U.S. Salinity Laboratory staff, 1954). The SAR is an indirect expression of the tendency of irrigation water to enter into ion exchange reactions in the soil. The SAR is calculated by the following equation:

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{++} + \mathrm{Mg}^{++}}{2}}}$$

where ion concentrations are expressed in milliequivalents per litre. Proportionately, a high sodium concentration, compared to the sum of calcium and magnesium, will yield a high SAR value. The classification scheme (for low sodium waters) developed by the U.S. Salinity Laboratory Staff (1954) is presented on Figure 19, a graphic plot of SAR (sodium hazard) versus electrical conductivity (salinity hazard).

Over half of the water samples collected in the basin fall into the C2-S1 class, which reflects a medium - salinity, low sodium hazard. These waters may be used for irrigation on most soils including clays and tills. Seventeen of the samples fall into the C3-S1, class in which the salinity hazard is high. These waters should only be used where adequate drainage is present. Four samples, all collected from wells finished in the Queenston shale, fall into the C3-S2 and C4-S2 classes. These waters should not be used for irrigation except under special soil management conditions. The local agricultural representative should be contacted where there is doubt as to the suitability of a water for irrigation.



LEGEND

× Surface-water sample

● Ground-water sample

SALINITY HAZARD

C1 **Low-Salinity Water** can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

C2 **Medium-Salinity Water** can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

C3 **High-Salinity Water** cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

C4 **Very High Salinity Water** is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

SODIUM HAZARD

S1 **Low-Sodium Water** can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

S2 **Medium-Sodium Water** will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

Figure 19. Suitability of water for irrigation, classified on the basis of sodium and salinity hazards (diagram and legend after U.S. Salinity Laboratory Staff, 1954).

SUMMARY

This investigation evaluates the ground-water resources of the East and Middle Oakville Creeks drainage basin in terms of their hydrogeologic setting, quality and useability. Included in the report are original data and associated analyses describing the geology, principal aquifers and major water uses in the area and the results of a simplified hydrologic budget. The results of the investigation are summarized below.

The drainage basin is representative of a larger area of southern Ontario characterized by the Niagara Escarpment and a clay and clay-till plain. The basin overlaps three physiographic regions: the Niagara Escarpment, the South Slope and the Peel Plain. The Niagara Escarpment, unique to western New York State and this part of southern Ontario, is a cliff of erosion-resistant Silurian dolostone. The South Slope is divided by the Peel Plain into a northern portion of ground moraine and outwash deposits, draping the base of the Escarpment and a southern portion comprised of the Trafalgar Moraine and adjacent till plain. The Peel Plain is an area of clay soils of low relief created by a blanket of glaciolacustrine sediments deposited in a short-lived glacial lake (Peel Ponding).

The East and Middle Oakville creeks rise in the plain just west of the scarp area, descend the Escarpment where they cut across the South Slope and Peel Plain in an easterly direction, to merge in a deeply incised bedrock valley near Drumquin. The drainage basin area is approximately 79 square miles.

The basin lies within the South Slope and Huron Slope climatic regions. The South Slope climatic region as typified by the climatic data (for 1969-1974) collected at the Hornby IHD station, has a mean annual precipitation of 33.17 inches and mean annual temperature of 44.8°F. The Huron Slope region is wetter and cooler having a mean annual precipitation of 36.13 inches and mean annual temperature of 43.1°F (for the same interval, measured at the Speyside IHD station).

The bedrock underlying the basin ranges in age from the Upper Ordovician (east) to the Middle Silurian (west). The oldest stratigraphic unit is the Queenston Formation (shale) exposed below the Escarpment in the bedrock drainage channel. The Silurian formations are exposed along the scarp in quarries and outcrops. These include the Whirlpool Formation (a quartzose sandstone), the Manitoulin Formation (a dolostone), the Cabot Head Formation (a shale), and the Reynales and Amabel formations (dolostones). The bedrock units dip gently to the west. The bedrock surface has a relief of approximately 675 feet, ranging from a height of 1198 feet west of the Escarpment to a low of 522 feet in the southeast (Map 1).

The surficial deposits consist of sediments of Pleistocene and Recent age. They include glacial tills, glaciofluvial sand and gravel, stratified glaciolacustrine clays, silt and sand and alluvium and muck (Map 2). Overburden thickness ranges from 0 to 35 feet above the Escarpment to 0 to 135 feet below the Escarpment.

Ground water is the major source of domestic water supply. The principal hydrogeologic units are the Halton and Wentworth tills, the Outwash and Channel Sand and Gravel deposits, the Amabel

Formation and the Queenston Formation. The tills and the Queenston Formation act as aquitards, although locally, they may yield sufficient supplies to meet domestic requirements. The Outwash and Channel Sand and Gravel deposits and the Amabel Formation are the principal aquifers.

The hydraulic properties of the bedrock and overburden were estimated by different methods, the resultant means and ranges of the coefficients of transmissibility and permeability and storage are presented below:

Aquifer - Method	Coefficient of Transmissibility Range (Igpd/ft)	Coefficient of Permeability Range (Igpd/ft^2)	Coefficient of Storage Range
OUTWASH SAND AND GRAVEL			
- pumping tests	$(0.3 \text{ to } 5) \times 10^5$	$(0.5 \text{ to } 5.8) \times 10^3$	10^{-1} to 10^{-6}
- grain-size distribution		$(0.6 \text{ to } 90) \times 10^2$	
AMABEL FORMATION			
- pumping tests	$(0.1 \text{ to } 10) \times 10^4$		10^{-2} to 10^{-5}
- specific-capacity values	3.8×10^2 (median value)		
- specific capacity values (Coward and Barouch, 1978)	3.2×10^3 (median value)		
- pumping tests (Coward and Barouch, 1978)	3.1×10^3 (median value)		

The direction of ground-water movement in the basin is, for the most part, down the regional slope from above the Niagara Escarpment towards Lake Ontario to the southeast. The water-level contour maps (Maps 6 and 7) are subdued replicas of the topographic surface map.

Water-level fluctuations in the basin follow a seasonal pattern with a rise in levels during the late winter-early spring and a decline during summer and fall. Based on the mean, long-term, water-level measurements for the observation wells finished in the basin, there has been a decline in the amount of water in storage from 1968 to 1974 of about one foot.

A simplified hydrologic budget was estimated for the different sub-basins for the water-year interval 1968-69 to 1973-74 using the following equation:

$$P = B + R_s + ET \pm \Delta S$$

where P = precipitation
B = ground-water runoff or baseflow
Rs = surface runoff
ET = evapotranspiration
ΔS = change in storage

The mean annual precipitation for this interval was 36.38 inches at Speyside and 33.91 inches at Hornby. Baseflow, estimated as a percentage of the total streamflow, range from 38.2% (4.93 inches precipitation/year) for the area including the Escarpment (0-1), 7.2% (0.65 inches) for the central area, a clay, clay-till plain (0-4) and 18.2% (1.89 inches) for the basin as a whole (0-5). The mean evapotranspiration estimated from temperature data (Munson-Index Method) generated at the different meteorological stations in the basin was 21.93 inches at Speyside and 22.97 inches at Hornby for the period of study.

Ground-water recharge for the basin was estimated to be 1.87 inches of precipitation per year. This value compares favourably with the baseflow estimates (baseflow assumed to be indicative of recharge) from the flow-duration curve (1.83 inches) and the hydrologic budget (1.89 inches).

A total of 40 permits to take water have been issued in the basin for water takings in excess of 10,000 Igpd. The allowable takings for irrigation purposes amount to 3.25 mgpd from surface water. The rural domestic water demand from wells in the basin is estimated to be an additional 0.24 mgpd.

A total of 46 stream and well samples were collected from within the basin in September 1974. For the most part, the analyses of these samples reflect certain chemical characteristics found in waters associated with carbonate and shale terrains. Samples collected from the Amabel Formation are of the calcium-magnesium-bicarbonate type and are typically hard. Samples collected from the Queenston Formation reflect a high variability in chemical composition being higher in total dissolved solids, sulphate, chloride and sodium content than samples collected from the other hydrogeologic units. The chemical quality of the ground-water samples collected from the overburden was variable, being lower in quality than the Amabel Formation samples and higher in quality then the samples from the Queenston Formation.

With certain localized exceptions (i.e. some of the water samples collected from the Queenston Formation) the majority of the samples are suitable for domestic and irrigation uses.

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APPENDIX A

MOE Observation Well Logs

TABLE 16. SUMMARY OF MOE OBSERVATION WELL RECORDS

Well No.	County	Township	Con.	Lot	Well Depth (feet)	Water Found at (feet)	Static Level (feet)	Screen Set at (feet)	Depth Interval (feet)	Geologic Log
0-2a	Halton	Esquesing	III	16	38.5	37-38.5	5.0	9.6-38.5[1]	0-5	Brown, sand, stones
									5-25	White-grey, dolomite
									25-38.5	Black-grey, dolomite
0-2b	Halton	Esquesing	VII	06	44	25	8.7	11[2]	0-20	Brown, stoney clay till
							13.2	26[2]	20-34	Grey, stoney clay till
							13.3	36[2]	34-44	Red, shale (Queenston)
0-3	Halton	Esquesing	III	11	128	70	10.5	47[4]	0-4	Brown, fine grained, sand
						92	10.5	85[4]	4-8	Brown, clay till
							10.0	128[2]	8-70	Brown, well sorted, fine grained, sand
									70-92	Brown, well sorted, fine to medium grained, sand
									92-104	Medium grained, gravel (mostly Queenston shale)
									104-128	Red, shale (Queenston)
0-4a	Halton	Esquesing	VIII	02	190	15-17	2.4	35[2]	0-10	Brown, clay till
						27-45	1.6	60[2]	10-20	Grey, very stoney, till
						50-68	3.4	94[3]	20-26	Grey, stoney, till
									26-40	Brown, medium grained, sand
									40-50	Grey, very stoney, till
									50-62	Fine grained, gravel
									62-68	Brown, fine grained, sand
									68-190	Red, shale (Queenston)

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[1] - open hole

[2] - (slotted pipe (1-1/4 inch)), 3 to 5-foot length

[3] - (slotted pipe (1-1/4 inch)), 15-foot length

[4] - sand point

TABLE 16. SUMMARY OF MOE OBSERVATION WELL RECORDS (continued)

Well No.	County	Township	Con.	Lot	Well Depth (feet)	Water Found at (feet)	Static Level (feet)	Screen Set at (feet)	Depth Interval (feet)	Geologic Log
0-4b	Halton	Esquesing	V	04	98		7.8	30[4]	0-22	Brown, clay and gravel till
							6.9	60[4]	22-68	Brown, sand 44-46 clay streak
							8.0	98[2]		53-55 clay streak
									68-98	Shale (Queenston)
0-4c	Halton	Esquesing	VII	06	96	57	4.5	50[4]	0-16	Brown, clayey till (with fine to medium pebbles)
							3.8	89[2]	16-30	Gray, sandy till (with clay and pebbles)
							2.3	96[2]	30-31	Brown, fine grained, sand
									31-44	Gray, sandy till (with clay and pebbles)
									44-57	Brown, fine grained, sand
									57-66	Medium grained, gravel
									66-96	Shale (Queenston)
0-5	Halton	Oakville	VI	01	50	5	8.0	8-50[1]	0-5	Reddish, till
									5-50	Red, shale (Queenston)

[1] - open hole

[2] - (slotted pipe (1-1/4 inch)), 3 to 5-foot length

[3] - (slotted pipe (1-1/4 inch)), 15-foot length

[4] - sand point

APPENDIX B

Chemical Analyses of Water Samples

Sample No.	pH (field)	Specific Conductance mmhos @ 25°C (Lab)	Total Dissolved Solids (TDS)	Temperature (field)	Hardness ppm $CaCO_3$	Total Iron ppm	Bicarbonate Alkalinity ppm HCO_3 (Lab)	CATIONS								ANIONS								SAR	Error = $\frac{\text{Cations-Anions}}{\text{Cations+Anions}}$ x100%
								Bicarbonate Alkalinity HCO_3 (field)		Chloride Cl		Sulphate SO_4		Nitrate as N		Calcium Ca		Magnesium Mg		Sodium Na		Potassium K			
								ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm		
SHALE - QUEENSTON FORMATION																									
4	7.00	2100	1684	14	896	12.0	492	460	9.19	190	5.36	500	10.41	<.2	0.01	110	5.49	151	12.42	156	6.79	15.0	0.38	2.27	0.2
5	7.00	810	687	9.5	428	3.6	359	332	6.63	17	0.48	97	2.02	<.2	0.01	117	5.84	33	2.72	16	0.70	1.4	0.04	0.34	0.7
6	6.90	1060	775	12	450	0.05	437	388	7.75	45	1.27	64	1.33	<.2	0.04	68	3.39	68	5.59	46	2.00	8.5	0.22	0.94	3.7
7	7.05	560	446	14	290	0.3	255	224	4.48	6	0.17	60	1.25	0.6	0.01	60	2.99	34	2.80	7	0.30	4.9	0.12	0.18	2.5
8	6.80	1100	833	11	566	1.0	295	260	5.20	71	2.00	200	4.16	<.2	0.49	149	7.44	47	3.87	12	0.52	6.9	0.18	0.22	0.6
11	7.40	1300	789	14	282	0.3	84	56	1.12	185	5.22	300	6.25	<.2	0.01	43	3.49	26	2.14	2	5.66	1.7	0.23	3.37	-4.5
19	6.80	2150	1497	18	710	0.85	254	216	4.32	272	7.67	530	11.04	<.2	0.01	136	6.79	90	7.40	189	8.22	16.0	0.41	3.09	-0.5
20	6.80	3400	2671	19	1418	1.9	293	268	5.36	495	13.96	1000	20.82	<.2	0.01	248	12.38	194	15.96	392	17.05	14.0	0.36	4.53	6.5
21	6.70	2000	1493	11	665	3.4	517	360	7.19	74	2.09	650	13.53	<.2	0.01	128	6.39	84	6.91	98	4.26	19.0	0.49	1.65	-11.7
22	6.95	1700	1169	19	371	0.75	95	68	1.36	221	6.23	470	9.78	<.2	0.01	96	4.79	32	2.63	255	11.09	11.0	0.28	5.76	3.9
26	7.00	1380	1180	13	771	0.1	264	240	4.80	12	0.34	550	11.45	1.2	0.17	228	11.38	49	4.03	21	0.91	17.0	0.44	0.33	0.0
36	7.50	1420	1038	15	275	<.05	243	212	4.24	144	4.06	300	6.25	1.0	0.07	82	4.09	17	1.44	215	9.26	17.0	0.44	5.64	2.2
38	7.60	930	658	16	93	<.05	239	216	4.32	133	3.75	35	0.73	<.2	0.09	24	1.20	8	0.66	173	7.52	16.0	0.41	7.81	4.9
39	6.90	1100	694	15	546	<.05	364	240	4.80	114	3.22	63	1.31	1.4	0.10	166	8.28	32	2.63	19	0.83	1.0	0.03	0.35	11.1

TABLE 17. CHEMICAL ANALYSES OF WATER SAMPLES COLLECTED IN BASIN

Sample No.	pH (field)	Specific Conductance mmhos @ 25°C (Lab)	Total Dissolved Solids (TDS)	Temperature (field)	Hardness ppm $CaCO_3$	Total Iron ppm	Bicarbonate Alkalinity ppm HCO_3 (Lab)	C A T I O N S								A N I O N S								SAR	Error = $\frac{\text{Cations-Anions}}{\text{Cations+Anions}}$ x100%
								Bicarbonate Alkalinity HCO_3 (field)		Chloride Cl		Sulphate SO_4		Nitrate as N		Calcium Ca		Magnesium Mg		Sodium Na		Potassium K			
								ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm		
	OVERBURDEN SAMPLES																								
3	7.50	275	202	12	113	0.45	95	84	1.68	14	0.40	24	0.50	1.2	0.09	42	2.10	2	0.16	8	0.35	4.3	0.11	0.33	1.1
9	7.05	270	200	18	111	0.55	133	112	2.24	2	0.06	13	0.27	<.2	0.01	43	2.15	1	0.08	2	0.09	1.7	0.04	0.08	-4.5
10	6.80	1040	681	14	271	0.2	103	96	1.92	87	2.45	300	6.25	<.2	0.01	69	3.44	24	1.97	78	3.39	5.1	0.13	2.06	-8.6
12	6.85	1180	982	18	629	0.4	526	468	9.35	14	0.40	180	3.75	<.2	0.01	64	3.19	114	9.38	33	1.44	5.2	0.13	0.57	2.3
13	6.65	1300	843	10.5	590	0.1	289	252	5.04	214	6.04	70	1.46	3.6	0.26	162	8.08	45	3.70	27	1.17	1.3	0.03	0.48	0.8
14	6.90	1600	1184	13	679	0.3	373	268	5.36	112	3.16	420	8.74	<.2	0.01	107	5.34	100	8.23	110	4.78	7.8	0.20	1.84	3.6
17	6.85	1060	758	13	434	<.05	205	200	4.00	67	1.89	73	1.52	32	2.29	144	7.19	18	1.48	17	0.74	53	1.36	0.36	5.2
18	7.15	1120	656	12	221	1.5	228	128	2.56	265	7.48	9	0.19	1.2	0.09	49	2.44	24	1.97	145	6.31	2.6	0.07	4.24	2.3
24	7.00	580	484	11.5	318	0.4	200	272	5.44	5	0.14	22	0.46	<.2	0.01	96	4.79	19	1.56	7	0.30	2.4	0.06	0.17	5.3
25	7.10	580	463	16.5	315	0.9	319	252	5.04	5	0.14	31	0.64	<.2	0.01	93	4.64	20	1.64	4	0.17	1.5	0.04	0.10	5.4
27	6.80	690	570	17	378	<.05	329	296	5.92	5	0.14	53	1.10	2.8	0.08	112	5.59	24	1.97	7	0.30	2.4	0.06	0.16	4.5
28	6.90	640	523	10	347	<.05	287	260	5.20	34	0.96	26	0.54	<.2	0.20	88	4.39	31	2.55	13	0.56	1.9	0.05	0.30	4.6
29	6.70	580	457	14	319	0.5	255	228	4.56	13	0.37	43	0.90	4.0	0.01	98	4.89	18	1.48	4	0.17	1.8	0.05	0.10	6.1
30	6.55	820	618	16	431	<.05	292	256	5.12	76	2.14	49	1.02	0.8	0.29	125	6.24	29	2.39	7	0.30	1.9	0.05	0.15	2.3
32	7.00	560	558	15	358	0.05	317	28	5.60	11	0.31	38	0.79	7.4	0.53	102	5.09	25	2.06	7	0.30	1.3	0.03	0.16	1.8
33	7.45	540	466	11	295	0.05	296	256	5.12	6	0.17	33	0.69	0.4	0.03	62	3.09	34	2.80	15	0.65	2.0	0.05	0.38	4.7
34	7.20	630	494	16	289	<.05	250	220	4.40	41	1.16	44	0.92	<.2	0.01	109	5.44	4	0.33	26	1.13	0.7	0.02	0.67	3.2
35	7.20	740	569	16	334	0.10	237	208	4.16	30	0.85	77	1.60	11	0.79	114	5.69	12	0.99	13	0.56	21	0.54	0.31	2.6

TABLE 17. CHEMICAL ANALYSES OF WATER SAMPLES COLLECTED IN BASIN

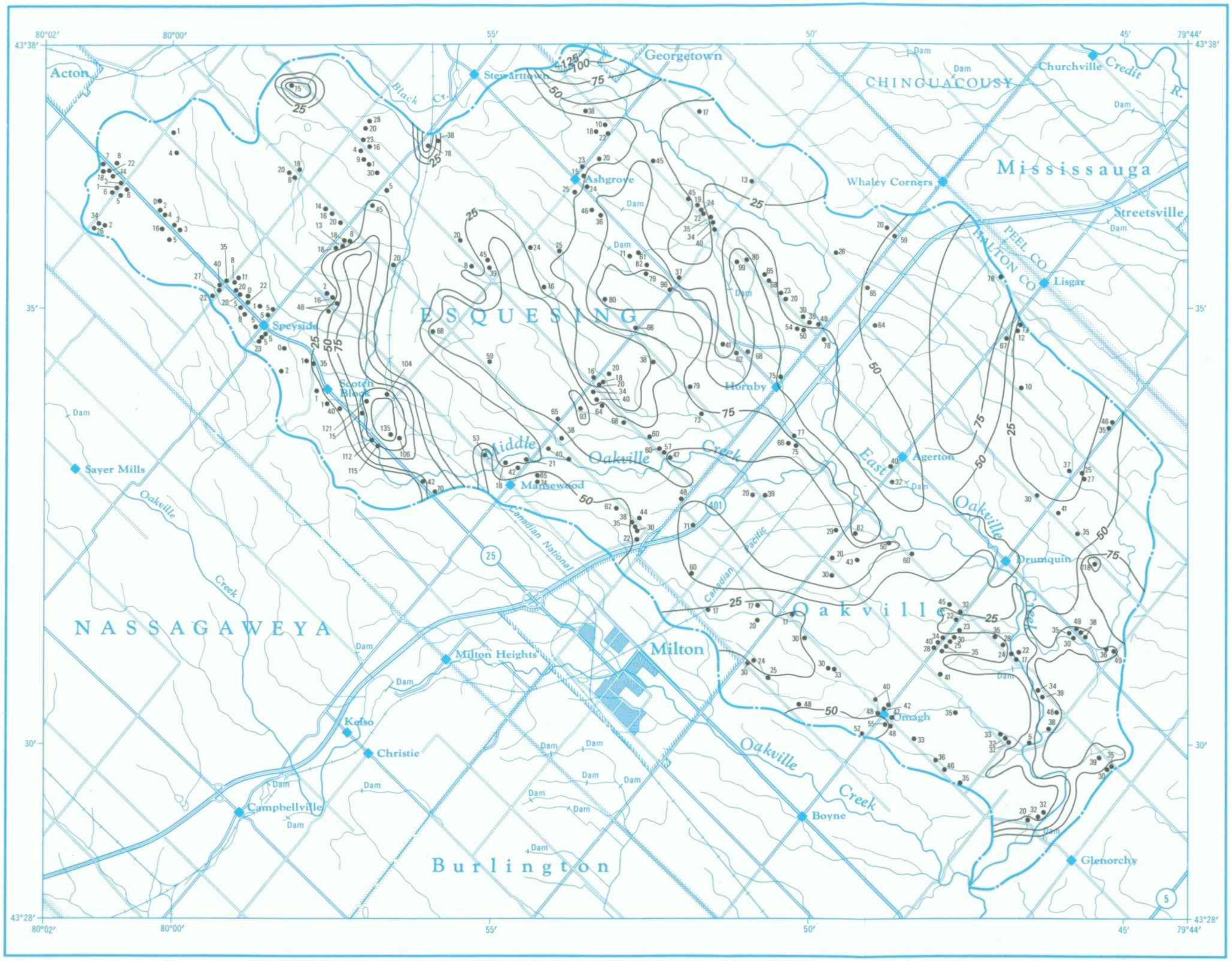
Sample No.	pH (field)	Specific Conductance mmhos @ 25°C (Lab)	Total Dissolved Solids (TDS)	Temperature (field)	Hardness ppm $CaCO_3$	Total Iron ppm	Bicarbonate Alkalinity ppm HCO_3 (Lab)	CATIONS								ANIONS								SAR	Error = $\frac{\text{Cations-Anions}}{\text{Cations+Anions}}$ x100%
								Bicarbonate Alkalinity HCO_3 (field)		Chloride Cl		Sulphate SO_4		Nitrate as N		Calcium Ca		Magnesium Mg		Sodium Na		Potassium K			
								ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm		
DOLOSTONE - AMABEL FORMATION																									
40	7.10	730	573	13	365	0.9	317	288	5.76	44	1.24	28	0.58	<.2	0.01	90	4.49	34	2.80	23	1.00	1.7	0.04	0.52	4.6
41	7.30	550	459	15	314	<.05	290	260	5.20	4	0.11	21	0.44	0.8	0.06	88	4.39	23	1.89	2	0.09	0.3	0.01	0.05	4.7
42	7.25	450	430	15	291	0.6	236	212	4.24	8	0.23	59	1.23	<.2	0.01	72	3.59	27	2.22	4	0.17	0.7	0.02	0.10	2.6
43	7.10	960	640	14	439	0.1	359	216	4.32	29	0.82	80	1.67	14.0	1.00	118	5.89	35	2.88	24	1.04	29	0.74	0.50	15.0
44	7.30	510	431	14	292	<.05	250	232	4.64	7	0.20	33	0.69	1.0	0.07	74	3.69	26	2.14	3	0.13	0.4	0.01	0.08	3.3
45	7.30	560	434	12	307	<.05	261	224	4.48	6	0.17	44	0.92	1.2	0.09	72	3.59	31	2.55	2	0.09	0.5	0.01	0.05	5.0
46	7.30	580	466	19	306	<.05	270	240	4.80	7	0.20	38	0.79	2.2	0.16	91	4.54	19	1.56	8	0.35	0.5	0.01	0.20	4.2
STREAM SAMPLES																									
1	7.60	420	337	14	212	0.5	183	172	3.44	18	0.51	30	0.62	<.2	0.01	54	2.70	19	1.56	4	0.17	1.0	0.03	0.12	-1.4
2	7.30	435	345	14	216	1.0	190	176	3.52	17	0.48	30	0.62	<.2	0.01	55	2.74	19	1.56	7	0.30	2.0	0.05	0.21	0.3
15	7.40	740	494	15	280	0.7	182	160	3.20	99	2.79	59	1.23	<.2	0.01	76	3.79	22	1.81	38	1.65	4.2	0.11	0.99	0.9
16	6.85	450	370	15	237	0.5	205	180	3.76	16	0.45	31	0.64	0.4	0.03	62	3.09	20	1.64	8	0.35	2.0	0.05	0.23	2.6
23	7.50	445	353	16	229	0.4	200	172	3.44	20	0.56	29	0.64	<.2	0.01	72	3.59	12	0.99	7	0.30	2.2	0.06	0.20	3.4
31	7.60	550	448	18	283	0.75	249	220	4.40	22	0.62	42	0.87	<.2	0.01	72	3.59	25	2.06	12	0.52	6.2	0.16	0.31	3.5
37	7.60	510	417	14	266	<.05	239	220	4.40	9	0.25	35	0.73	0.4	0.03	77	3.84	18	1.48	6	0.26	1.9	0.05	0.16	2.0

TABLE 17. CHEMICAL ANALYSES OF WATER SAMPLES COLLECTED IN BASIN

TD
403
.W77
no. 12
1979

Geology and water resources of
the East and Middle Oakville
Creeks IHD representative
drainage basin / Funk, Gunther.

76657



LEGEND

—75—	Line of equal overburden thickness (isopach), interval 25 feet
• 78	Overburden thickness from water-well records, in feet

SOURCES OF INFORMATION

Overburden thickness compiled by G. Funk and A. Babaris, 1975, from water-well records on file with the Ontario Ministry of the Environment.

Cartography by C. Lochan and R. Zimmermann.

Base map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic series.

To accompany Water Resources Report 12

Ontario
MINISTRY OF THE ENVIRONMENT
Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN

MAP 3

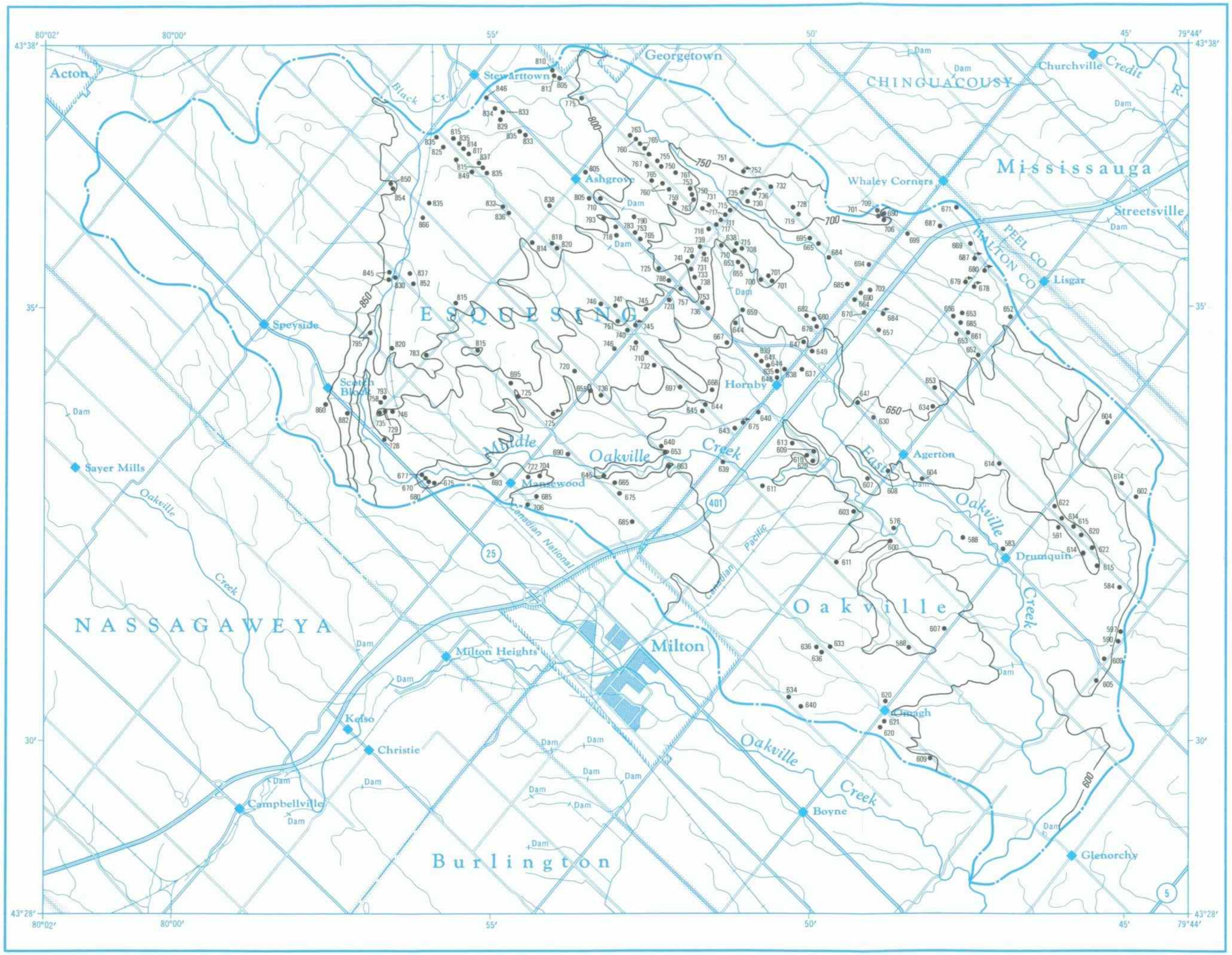
OVERBURDEN THICKNESS

Scale 1:100,000
1 inch equals 1.58 miles

1 0 1 2 3 Miles

1 0 1 2 3 4 5 Kilometres

Map 2170



LEGEND

750	Water-level contour, interval 50 feet
•	Water well ending in overburden
↙•	Flowing well ending in overburden
607	Water level

SOURCES OF INFORMATION

Water-level contours compiled by G. Funk and A. Babaris, 1975, from water-well records on file with the Ontario Ministry of the Environment and from the surface topography.

Cartography by C. Lochan and R Zimmermann.

Base map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic series.

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EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN

MAP 6

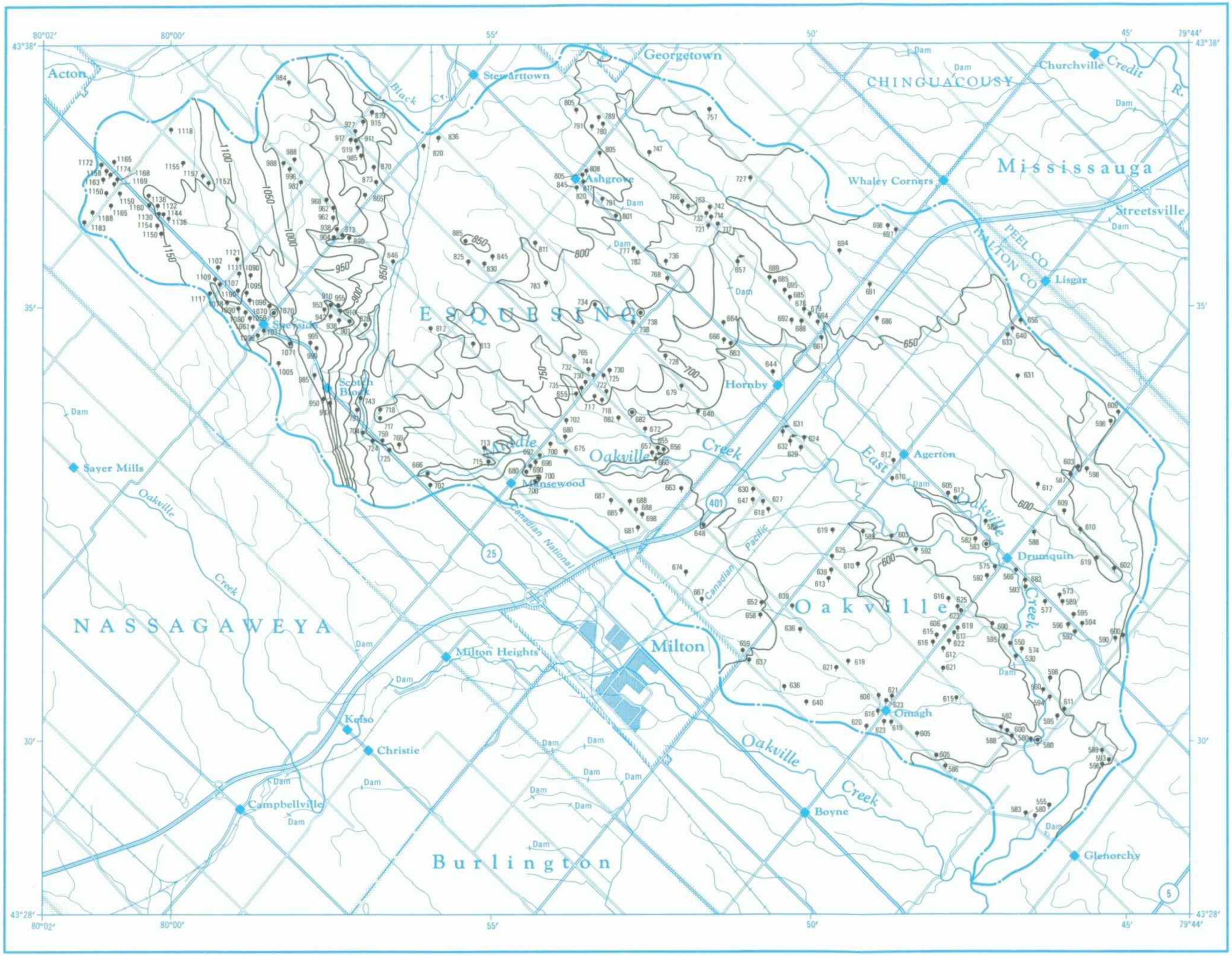
WATER LEVEL CONTOURS IN THE OVERBURDEN

Scale 1:100,000
1 inch equals 1.58 miles

1 0 1 2 3 Miles

1 0 1 2 3 4 5 Kilometres

Map 2173



LEGEND

650	Water-level contour, interval 50 feet
●	Water well ending in bedrock
●	Flowing well ending in bedrock
◉	Observation well ending in bedrock
658	Water level

SOURCES OF INFORMATION

Water-level contours compiled by G. Funk and A. Babaris, 1975, from water-well records on file with the Ontario Ministry of the Environment.

Cartography by C. Lochan and R. Zimmermann.

Base map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic series.

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MINISTRY OF THE ENVIRONMENT
Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN

MAP 7

WATER LEVEL CONTOURS IN THE BEDROCK

Scale 1:100,000
1 inch equals 1.58 miles

1 0 1 2 3 Miles

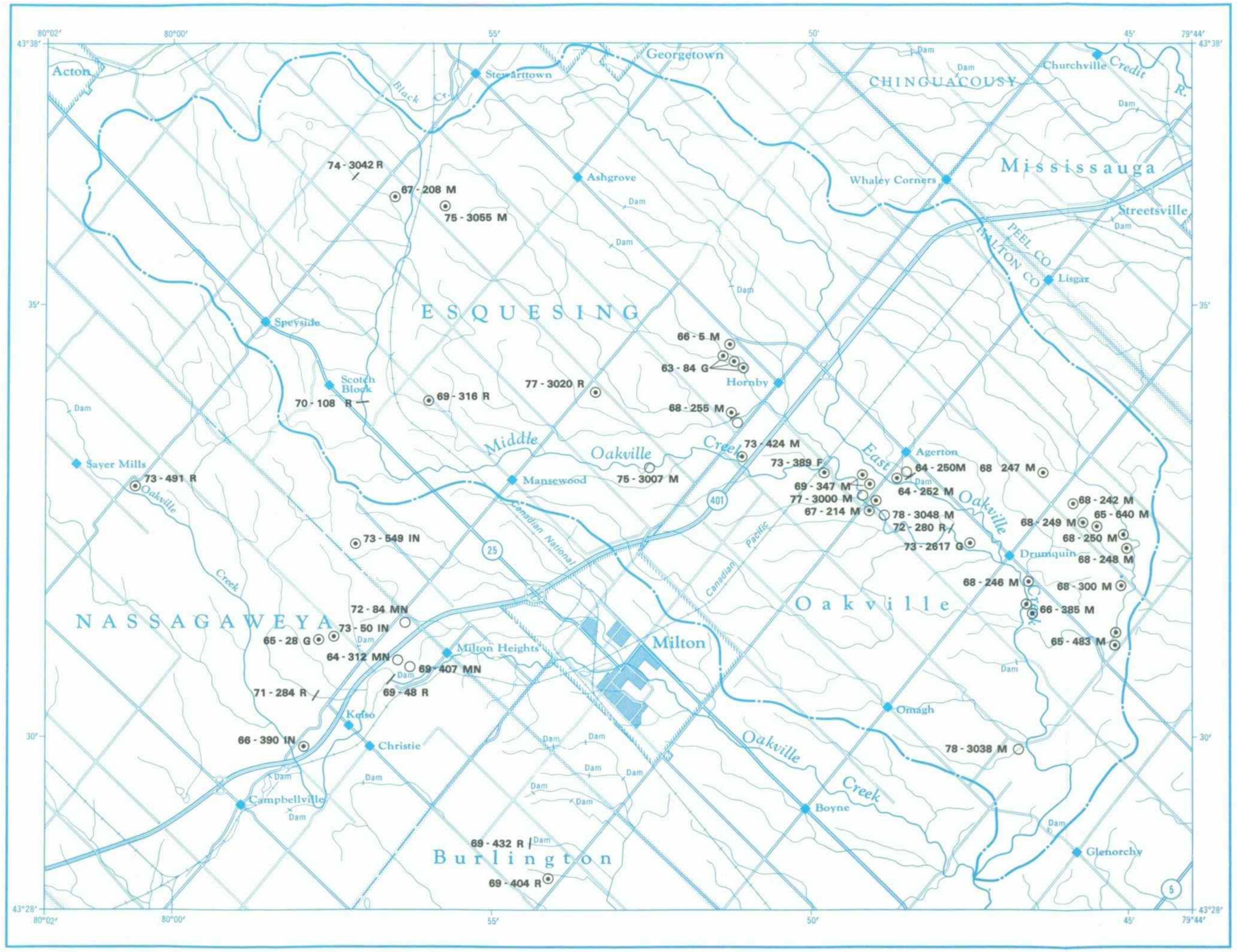
1 0 1 2 3 4 5 Kilometres

Map 2174

SUMMARY OF MAJOR WATER TAKINGS

MAP REFERENCE	SOURCE	AUTHORIZED	BY	PERMIT
		igpm		igpd
IRRIGATION				
78-3038	Surface Water	300		360,000
78-3048	Surface Water	300		105,000
77-3000	Surface Water	669		400,000
75-3007	Surface Water	91		–
75-3055	Surface Water	1300		300,000
73-2617	Surface Water	150		216,000
73-424	Surface Water	208		149,760
73-389	Surface Water	221	SC*	77,520
69-347	Surface Water	280		134,400
68-300	Surface Water	105		151,080
68-255	Surface Water	140	SC	134,400
68-242	Surface Water	105		37,800
68-246	Surface Water	288		69,200
68-247	Surface Water	160		19,200
68-248	Surface Water	204		98,000
68-249	Surface Water	120		43,200
68-250	Surface Water	108		90,800
67-208	Surface Water	53		11,520
67-214	Surface Water	270		360,000
66-385	Surface Water	128		184,300
66-5	Surface Water	50		30,000
65-640	Surface Water	50		15,000
65-483	Surface Water	108		78,000
65-28	Surface Water	291		52,500
64-252	Surface Water	172		52,250
64-250	Surface Water	334		80,000
63-84	Surface Water	20		S.C.
Total		6225		3,249,930
RECREATION				
77-3020	Surface Water	S.C.		S.C.
74-3042	Surface Water	S.C.		S.C.
73-491	Surface Water	S.C.		S.C.
72-280	Surface Water	S.C.		S.C.
71-284	Surface Water	S.C.		S.C.
70-108	Surface Water	S.C.		S.C.
69-316	Surface Water	S.C.		S.C.
69-48	Surface Water	S.C.		S.C.
MUNICIPAL				
72-84	Ground Water	50		48,000
69-407	Ground Water	1,400		2,000,000
64-312	Ground Water	700		1,000,000
Total		2,150		3,048,000
INDUSTRIAL				
73-549	Surface Water	1,410		2,030,000
66-390	Surface Water	333		480,000
Total:		1,743		2,510,000

S.C.*= Special Condition (Indicated on permit)



LEGEND

○ Well or Sandpoint	IN Industrial
⊙ Dugout, not connected to stream	MN Municipal
Dugout, connected to stream	R Recreational
Dugout, on-stream pond	G Golf course irrigation
Withdrawal from watercourse	M Market garden and nursery irrigation
Storage	F Agricultural field crop irrigation
Storage and Withdrawal	

73-549 IN Water-taking, refer to table for summary

SOURCES OF INFORMATION

Ministry of the Environment internal files associated with the Permit to Take Water program.

Water-well records on file with the Ontario Ministry of the Environment as of December 1974.

Cartography by C.Lochan.

Base map derived from 1:25,000 and 1:50,000 sheets of the National Topographic series.

◆

To accompany Water Resources Report 12

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Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN

MAP 8

GROUND — AND SURFACE — WATER TAKINGS

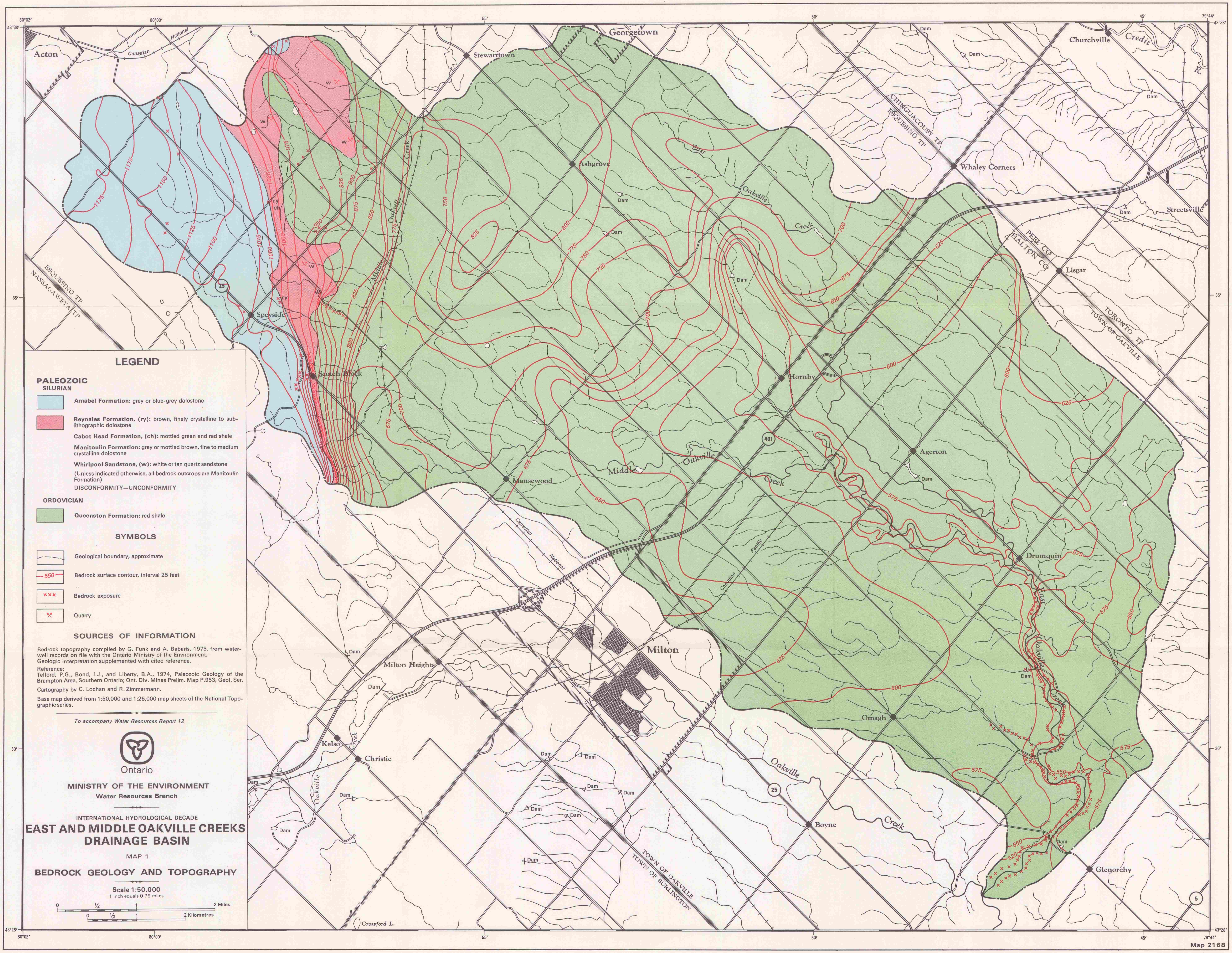
◆

Scale 1:100,000
1 inch equals 1.58 miles

1 0 1 2 3 Miles

1 0 1 2 3 4 5 Kilometres

Map 2216



LEGEND

PALEOZOIC
SILURIAN

🟦	**Amabel Formation:** grey or blue-grey dolostone
🟥	**Reynales Formation, (ry):** brown, finely crystalline to sub-lithographic dolostone
	Cabot Head Formation, (ch): mottled green and red shale
	Manitoulin Formation: grey or mottled brown, fine to medium crystalline dolostone
	Whirlpool Sandstone, (w): white or tan quartz sandstone
	(Unless indicated otherwise, all bedrock outcrops are Manitoulin Formation)
	DISCONFORMITY—UNCONFORMITY

ORDOVICIAN

🟩	**Queenston Formation:** red shale

SYMBOLS

– – –	Geological boundary, approximate
550	Bedrock surface contour, interval 25 feet
×××	Bedrock exposure
⚒	Quarry

SOURCES OF INFORMATION

Bedrock topography compiled by G. Funk and A. Babaris, 1975, from water-well records on file with the Ontario Ministry of the Environment. Geologic interpretation supplemented with cited reference.

Reference:
Telford, P.G., Bond, I.J., and Liberty, B.A., 1974, Paleozoic Geology of the Brampton Area, Southern Ontario; Ont. Div. Mines Prelim. Map P.953, Geol. Ser.

Cartography by C. Lochan and R. Zimmermann.

Base map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic series.

To accompany Water Resources Report 12

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN

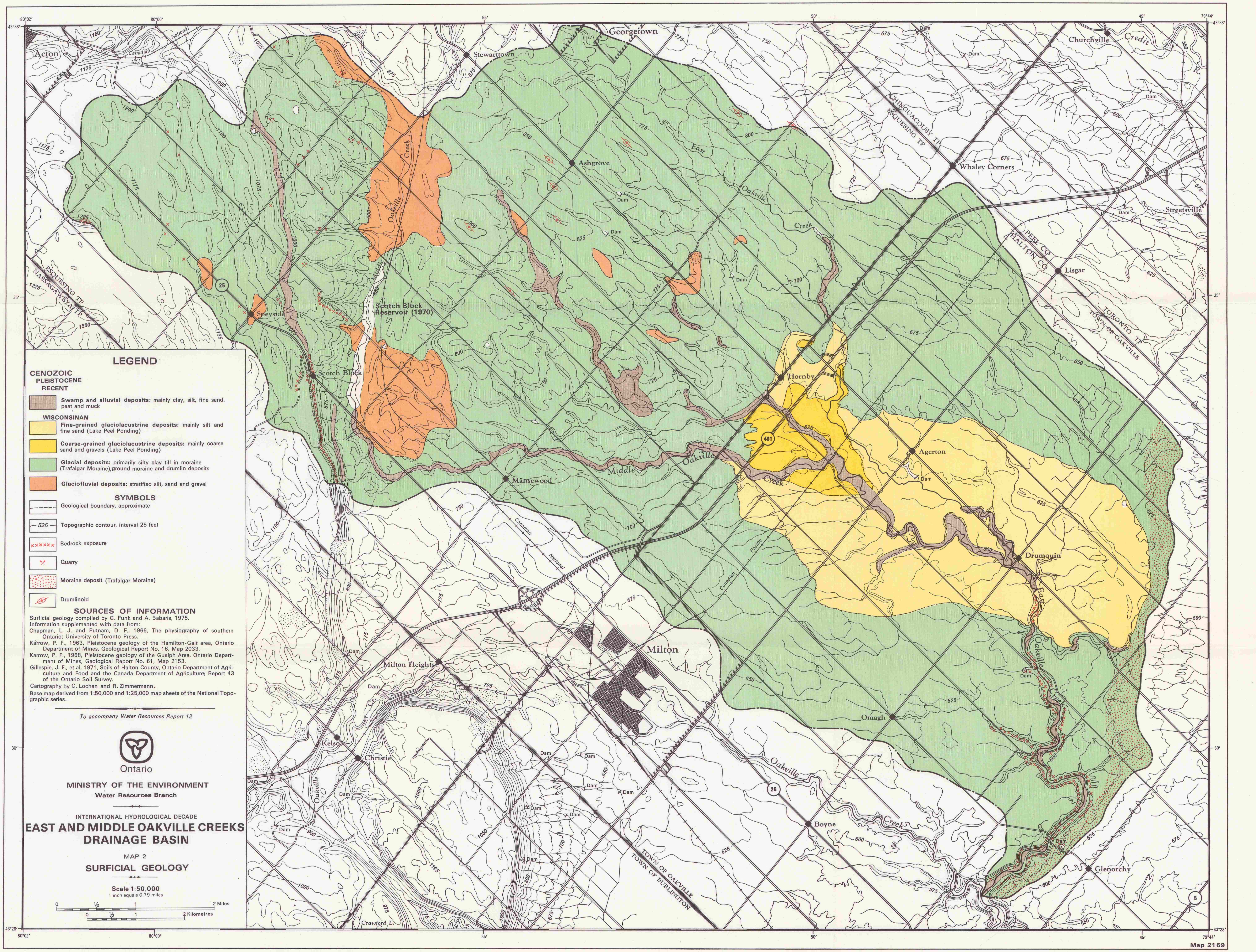
MAP 1

BEDROCK GEOLOGY AND TOPOGRAPHY

Scale 1:50,000
1 inch equals 0.79 miles

0 ½ 1 2 Miles
0 ½ 1 2 Kilometres

Map 2168



LEGEND

CENOZOIC
PLEISTOCENE
RECENT

🟫 **Swamp and alluvial deposits:** mainly clay, silt, fine sand, peat and muck

WISCONSINAN

🟨 **Fine-grained glaciolacustrine deposits:** mainly silt and fine sand (Lake Peel Ponding)

🟨 **Coarse-grained glaciolacustrine deposits:** mainly coarse sand and gravels (Lake Peel Ponding)

🟩 **Glacial deposits:** primarily silty clay till in moraine (Trafalgar Moraine), ground moraine and drumlin deposits

🟧 **Glaciofluvial deposits:** stratified silt, sand and gravel

SYMBOLS

- - - - Geological boundary, approximate

—525— Topographic contour, interval 25 feet

×××××× Bedrock exposure

⚒ Quarry

∴ Moraine deposit (Trafalgar Moraine)

⊘ Drumlinoid

SOURCES OF INFORMATION

Surficial geology compiled by G. Funk and A. Babaris, 1975.
Information supplemented with data from:

Chapman, L. J. and Putnam, D. F., 1966, The physiography of southern Ontario; University of Toronto Press.

Karrow, P. F., 1963, Pleistocene geology of the Hamilton-Galt area, Ontario Department of Mines, Geological Report No. 16, Map 2033.

Karrow, P. F., 1968, Pleistocene geology of the Guelph Area, Ontario Department of Mines, Geological Report No. 61, Map 2153.

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Cartography by C. Lochan and R. Zimmermann.

Base map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic series.

To accompany Water Resources Report 12

Ontario

MINISTRY OF THE ENVIRONMENT
Water Resources Branch

INTERNATIONAL HYDROLOGICAL DECADE

EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN

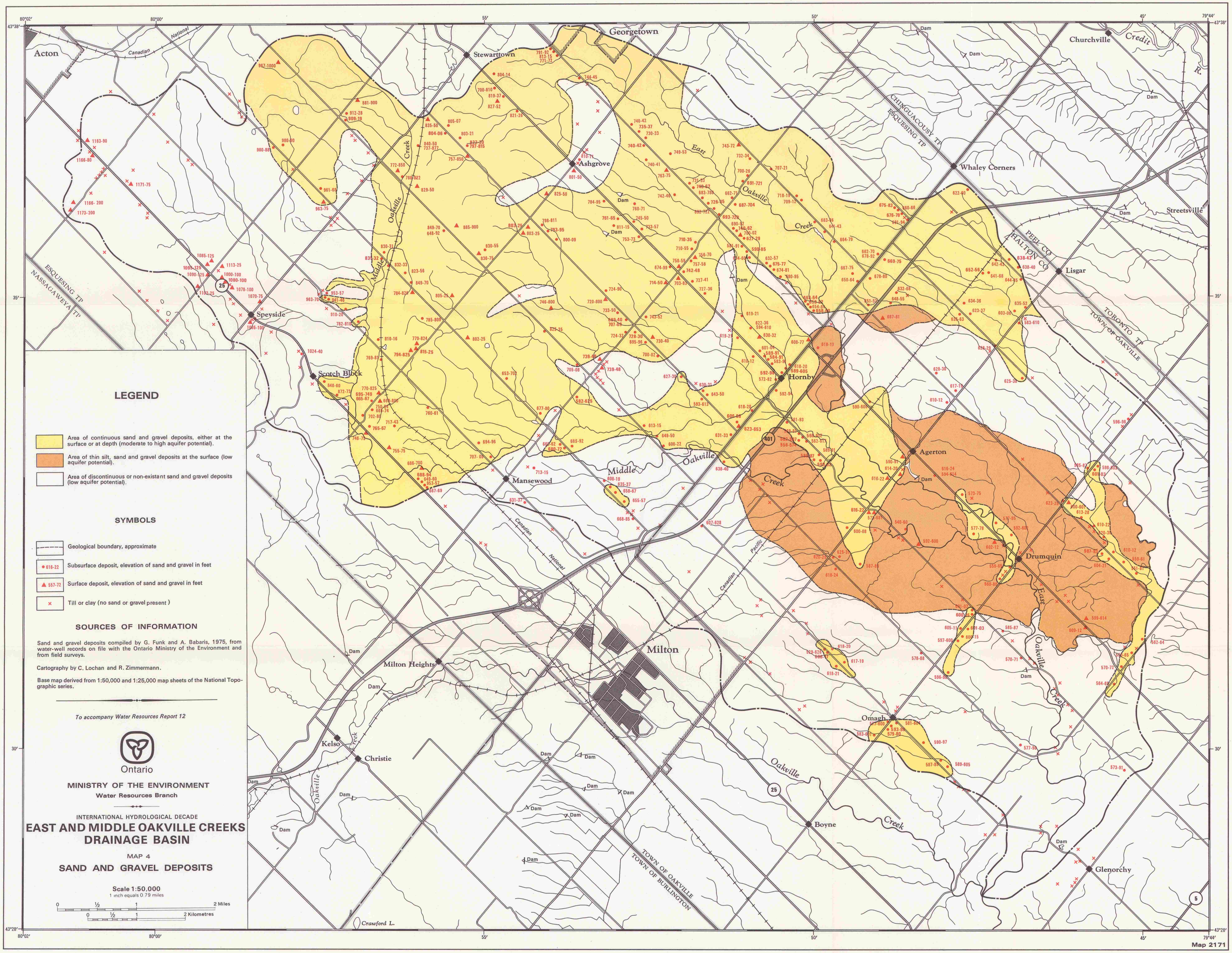
MAP 2

SURFICIAL GEOLOGY

Scale 1:50,000
1 inch equals 0.79 miles

0 ½ 1 2 Miles
0 ½ 1 2 Kilometres

Map 2169



LEGEND

🟨	Area of continuous sand and gravel deposits, either at the surface or at depth (moderate to high aquifer potential).
🟧	Area of thin silt, sand and gravel deposits at the surface (low aquifer potential).
☐	Area of discontinuous or non-existant sand and gravel deposits (low aquifer potential).

SYMBOLS

– – – –	Geological boundary, approximate
● 616-22	Subsurface deposit, elevation of sand and gravel in feet
▲ 557-72	Surface deposit, elevation of sand and gravel in feet
×	Till or clay (no sand or gravel present)

SOURCES OF INFORMATION

Sand and gravel deposits compiled by G. Funk and A. Babaris, 1975, from water-well records on file with the Ontario Ministry of the Environment and from field surveys.

Cartography by C. Lochan and R. Zimmermann.

Base map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic series.

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EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN

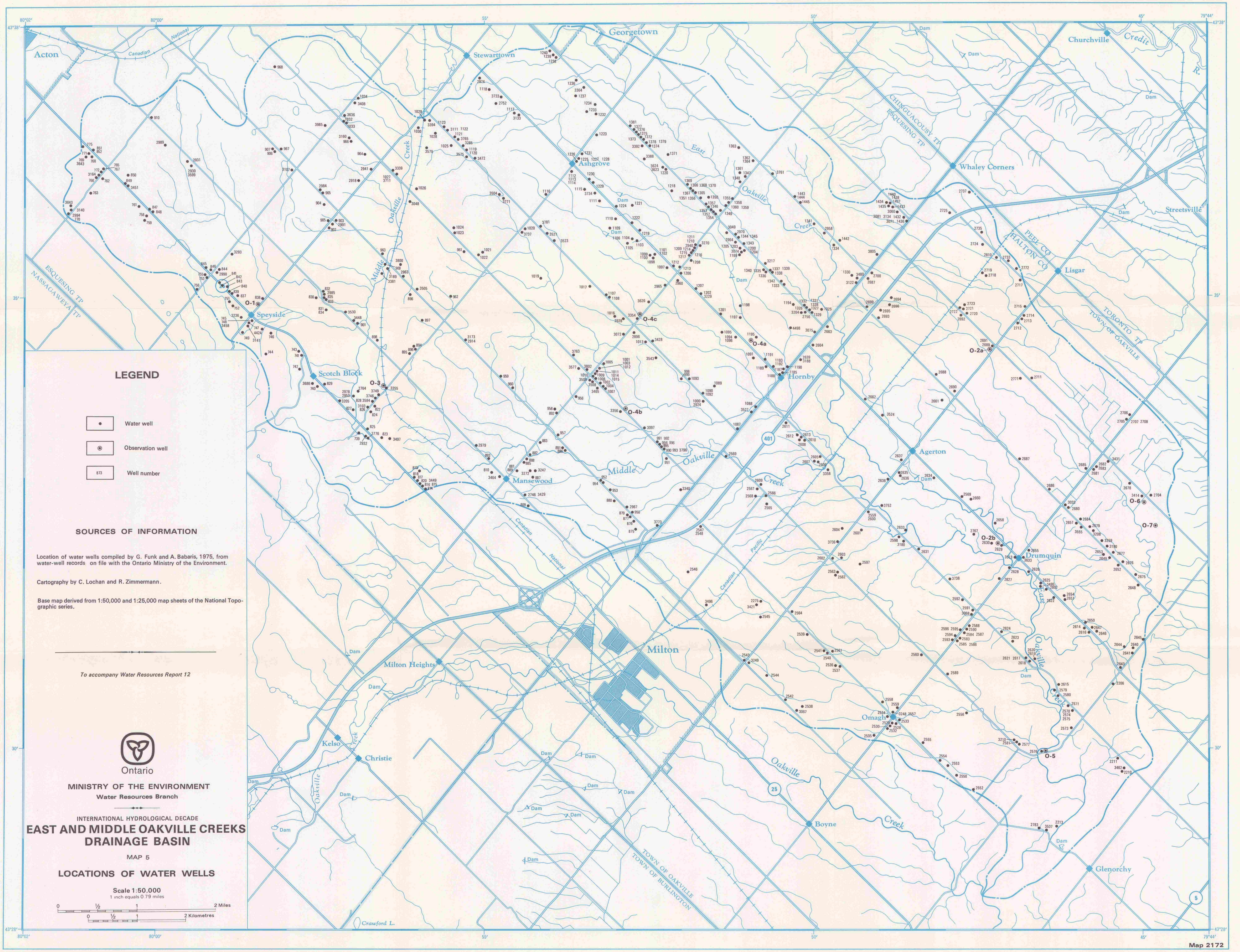
MAP 4

SAND AND GRAVEL DEPOSITS

Scale 1:50,000
1 inch equals 0.79 miles

0 ½ 1 2 Miles
0 ½ 1 2 Kilometres

Map 2171



LEGEND

•	Water well
⦿	Observation well
873	Well number

SOURCES OF INFORMATION

Location of water wells compiled by G. Funk and A. Babaris, 1975, from water-well records on file with the Ontario Ministry of the Environment.

Cartography by C. Lochan and R. Zimmermann.

Base map derived from 1:50,000 and 1:25,000 map sheets of the National Topographic series.

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EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN

MAP 5

LOCATIONS OF WATER WELLS

Scale 1:50,000
1 inch equals 0.79 miles

0 ½ 1 2 Miles
0 ½ 1 2 Kilometres

Map 2172